TRANSACTIONS OF THE

American Foundrymen's Association

Proceedings of the

Twenty-ninth Annual Meeting

SYRACUSE, NEW YORK

October 5 to 9, 1925

VOLUME XXXIII

Edited by ROBERT E. KENNEDY

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Summary of the Proceedings of the Twenty-Ninth Annual Meeting

Syracuse, N. Y., Oct. 5 to 9, 1925

The twenty-ninth annual meeting of the American Foundrymen's Association and nineteenth annual exhibit of foundry equipment was held at the New York State Fairgrounds, Syracuse, N. Y., October 5th to 9th inclusive. As has been customary for the past few years, the Institute of Metals Division of the A. I. M. E. held its fall meeting in conjunction with the meeting of the A. F. A., three joint sessions of the two associations being conducted.

The nineteenth annual exhibit of foundry equipment, machines and supplies, installed in buildings on the State Fair Grounds, was in some respects the best ever shown at A. F. A. conventions.

Manufacturers' Building, 500 feet long and 125 feet wide, with its two wings, provided 46,217 square feet, exclusive of aisles. There were no restrictions as to floor-load, and unlimited head-room offered exceptional opportunities for making display.

Total exhibit space occupied at Syracuse was 57,370 square feet. One hundred and eighty-seven firms exhibited, using an average of 306 square feet of floor space. Total space used at Milwaukee in 1924 was 55,164 square feet. In total of exhibit space used at A. F. A. exhibitions, Syracuse ranks third; Philadelphia, 1919, second, with 60,400 square feet, and Columbus, 1920, first, with 76,600 square feet.

The total number of freight cars unloaded from siding at Fair Grounds was 74, the total tonnage of exhibits was approximately 800. Transformer capacity required was 600 K. V. W., and the total number of motors connected was 135. Among the larger motors there was one for 100 H. P., one 75 H. P., one 60 H. P., and two 50 H. P.

Of the fifteen technical sessions held, three were joint meetings with the Institute of Metals Division of the A. I. M. E. Forty-five papers as A. F. A. contributions were presented, two being exchange papers of the Institute of British Foundrymen and the Association Technique de Fonderie de France. Ten committee reports were read. Inovations in technical sessions were the round table discussions on brass foundry problems and foundry refractories and the meeting of instructors of foundry practice of technical schools.

The technical papers presented were divided as follows:

5—Brass and Bronze.
4—Aluminum and Aluminum Alloys.
11—Cast Iron Founding and Metallurgical.
3—General Foundry Practice.
3—Foundry Costs.
3—Steel Founding and Metallurgical.
1—Foundry Safety.
9—Sand Testing and Control.
6—Malleable Founding and Metallurgical.

The I. B. F. exchange paper, "Some Inter-Relationships in Cast Iron, Wrought Iron and Steel Practice," was read in person by the author, J. E. Fletcher, consultant to the British Cast Iron Research Association. The French exchange paper "Some Notes on the Founding of Light Alloys," by R. de Fleury of Paris, was read by Dr. R. J. Anderson, who had translated the paper.

A detailed summary of the technical sessions follows:

Session No. 1—Non-Ferrous Founding.
Joint Session A. F. A. and Institute of Metals Division, A. I. M. E.,
Monday, October 5, 2:00 p. m.

President L. W. Olson in the chair, with G. K. Elliott, chairman of the Institute of Metals Division, as associate chairman.

Papers read were as follows:

SOME REFRACTORY PROBLEMS IN THE NON-FERROUS ELECTRIC FURNACE CASTING SHOP, by G. F. Hughes, Bridgeport Brass Co., Bridgeport, Connecticut—presented by the author.

TEMPERATURE CONTROL OF NON-FERROUS ALLOYS, by R. L. Binney, The Bunting Brass and Bronze Co., Toledo, Ohio—presented by the author.

ATOMIZED COAL SYSTEM OF NON-FERROUS MELTING, by R. Black and C. L. Shafer, Gibralter Bronze Co., Cincinnati, Ohio—presented by R. Black.

MATERIAL HANDLING IN A BRASS FOUNDRY, by T. C. Flinn, Blake and Knowles Works, Worthington Pump and Machinery Corp., East Cambridge, Mass.—presented by the author.

NEW HIGH FREQUENCY INDUCTION FURNACES, by D. Willcox, Ajax-Electrothermic Corp., Trenton, N. J.—presented by the author.

Session No. 2—The Grey Iron Foundry.

Monday, October 5, 2:00 p. m.

Past-President L. L. Anthes in the chair.

The papers dealing with melting of cast iron were:

CONTINUOUS IRON TEMPERATURE RECORDING, by H. W. Dietert and W. M. Myler, Jr., the U. S. Radiator Corp., Detroit, Mich.—presented by H. W. Dietert.

THE EFFECT OF HEAT TREATMENT ON THE PROPERTIES AND MICROSTRUCTURE OF GREY CAST IRON AND SEMI-STEEL, by O. W. Potter, University of Minnesota. Presented on behalf of the Twin City Foundrymen's Association—presented by the author.

ELECTRIC MELTING OF CAST IRON, by G. E. Lamb, The Lamb Machine Co., Hoquiam, Wash.—presented by the author.

SYNTHETIC CAST IRON, by G. S. Schaller, University of Washington, Seattle, Washington—presented by the author.

Session No. 3—General Foundry Topics.

Tuesday, October 6, 10:00 a. m.

A. H. Jameson in the chair.

REDUCING COSTS OF CLEANING FERROUS CASTINGS, by J. H. Hopp, Hopp-Patterson Co., Chicago, Ill. Contributed on behalf of the Chicago Foundrymen's Club. In the absence of the author this paper was read in abstract form and discussed.

SOME INTER-RELATIONSHIPS IN CAST IRON, WROUGHT IRON AND STEEL PRACTICE, by J. E. Fletcher, British Cast Iron Research Association, Annual Exchange Paper of the Institute of British Foundrymen—presented by the author.

FOUNDRY PROGRESS, PAST, PRESENT AND FUTURE, by J. D. Towne, Dayton Steel Foundry Company, Dayton, Ohio—presented by the author.

Session No. 4—Aluminum and Aluminum Alloys
Joint Session A. F. A. and Institute of Metals Division, A. I. M. E.
Tuesday, October 6, 10:00 a. m.

W. M. Corse, secretary of the Institute of Metals Division, A. I. M. E., representing the Institute of Metals Division, in the chair, with Dr. Robert J. Anderson as associate chairman, representing the A. F. A.

The papers dealing exclusively with aluminum and aluminum alloy casting were:

ALUMINUM AND ALUMINUM ALLOYS IN AIR-CRAFT, by Samuel Daniels, Engr. Div. Air Service, U. S. A., McCook Field, Dayton, Ohio—presented by the author.

X-RAY EXAMINATION OF ALUMINUM ALLOY CASTINGS FOR INTERNAL DEFECTS, by R. J. Anderson, Cleveland, Ohio—presented by the author.

ALUMINUM-ALLOY PERMANENT MOLD CASTINGS, by J. B. Chaffe, Jr., Permold Company, Cleveland, Ohio—presented by the author.

MECHANICAL PROPERTIES OF ALUMINUM-COPPER-SILICON ALLOY AS SAND CAST AND AS HEAT TREATED, by Samuel Daniels and D. M. Waner, Air Service, U. S. A., McCook Field, Dayton, Ohio—contributed on behalf of the A. I. M. E. and presented by the author.

SOME NOTES ON THE FOUNDING OF LIGHT ALLOYS, by R. de Fleury, Paris, France.—Contributed as the annual exchange paper of the Association Technique de Fonderie de France and presented by Dr. R. J. Anderson.

Session No. 5—Brass Founding Problems
Joint Meeting of the A. F. A. and the Institute of Metals Division, A. I. M. E.

G. K. Elliott, chairman of the Institute of Metals Division, in the chair, with N. K. B. Patch representing the A. F. A.

The session was conducted as an informal discussion meeting following a luncheon gathering at the Hotel Syracuse. No record was made of the discussion which took place as it was desired that all feel especially free to bring up questions encountered in their shop practice. The discussion was largely based on the subject of the value of fluxes.

Session No. 6—Foundry Costs
Tuesday, Oct. 6, 1:30 p. m.

A. E. Hageboeck, chairman of the A. F. A. committee on Foundry Costs, in the chair.

After Chairman Hageboeck explained the aims of the work of the A. F. A. Committee on Foundry Costs, two papers were presented as follows:

FOUNDRY MANAGEMENT AND ITS EFFECTS ON FOUNDRY COSTS, by W. J. Barrett, Metropolitan Life Insurance Co., New York—presented by the author.

PRACTICAL FOUNDRY COST ACCOUNTING, by E. T. Runge, cost consultant, National Founders' Association, Cleveland, Ohio —presented by the author.

Session No. 7—Apprentice Training
Tuesday, October 6, 3:00 p. m.

Dr. C. B. Connelley, chairman of the A. F. A. committee on Apprentice Training, in the chair.

The meeting was given over to an informal discussion of apprentice training problems, the discussion centering about a list of printed questions which were furnished to those in attendance. The one paper read was:

WHAT THE FOUNDRY OFFERS A TECHNICAL GRADUATE AS VIEWED BY A GRADUATE APPRENTICE, by R. R. Meigs, West Lynn, Mass.—presented by the author.

Session No. 8—Foundry Refractories
Tuesday, October 6, 3:00 p. m.

C. N. Ring, chairman of the A. F. A. committee on Foundry Refractories, in the chair.

This meeting was conducted as a discussion group considering questions on malleable iron and steel foundry refractories problems. The list of questions was prepared by the members

of the A. F. A. committee on Refractories and is published elsewhere in this volume.

Session No. 9—Steel Foundry Practice
Wednesday, October 7, 10:00 a. m.

John Howe Hall in the chair.

The papers and reports presented were as follows:

MAKING MISCELLANEOUS CASTINGS FOR NAVY USE, by Lieutenant Commander D. F. Ducey, U. S. Navy Yard, Bremerton, Puget Sound, Washington—read by title.

CARBON STEEL AND CARBON-VANADIUM STEEL IN THE CONVERTER, by R. S. Robinson, Industrial Works, Bay City, Michigan—presented by the author.

NOTES ON THE PERFORMANCE OF A ONE AND A HALF TON ELECTRIC FURNACE by A. W. Gregg and N. R. Knox, Bucyrus Corporation, S. Milwaukee, Wisconsin—presented by N. R. Knox.

REPORT OF THE A. F. A. REPRESENTATIVE ON THE JOINT COMMITTEE ON INFLUENCE OF PHOSPHORUS AND SULPHUR ON STEEL, presented by R. A. Bull, A. F. A. representative on committee.

REPORT OF THE A. F. A. COMMITTEE ON SPECIFICATIONS FOR STEEL CASTINGS, presented by A. H. Jameson, chairman of the committee.

REPORT OF A. F. A. COMMITTEE ON HEAT TREATMENT OF FERROUS CASTINGS, presented by R. A. Bull, chairman of the committee.

Each committee report was accepted and approved as read.

Session No. 10

Session No. 10 was a session of the Institute of Metals Division of the A. I. M. E. and the report of this session will be found in the published proceedings of the American Institute of Mining and Metallurgical Engineers.

Session No. 11—General Papers and Committee Reports
Wednesday, October 7, 10:00 a. m.

Jesse L. Jones in the chair.

The following papers and committee reports were read:

REPORT OF THE COMMITTEE ON CORROSION OF FERROUS METALS presented by H. Y. Carson, chairman of the committee. Mr. Carson amplified his report by an illustrated talk on corrosion research.

SAFETY IN THE FOUNDRY, by R. G. Adair, Supervisor of Safety, The American Rolling Mill Co., Middletown, Ohio. Contributed on behalf of the Ohio State Foundrymen's Association—presented by J. P. Gatherum.

FOUNDRY COST ACCOUNTING, by C. H. Scovell, Scovell and Wellington, Springfield, Mass.—presented by the author.

The report of the committee on Corrosion of Ferrous Metals was accepted as a progress report.

Session No. 12—Business Meeting
Wednesday, October 7, 1:45 p. m.

President L. W. Olson in the chair.

The order of business taken up was as follows:

ANNUAL PRESIDENTIAL ADDRESS, read by President L. W. Olson.

REPORT OF THE SECRETARY-TREASURER, read by Secretary C. E. Hoyt.

REPORT OF THE NOMINATING COMMITTEE, read by Secretary C. E. Hoyt.

REPORT OF THE RESOLUTIONS COMMITTEE read by Director C. B. Connelley, chairman of the committee.

REPORT OF THE JUDGES OF OBERMAYER AWARD CONTEST, read by Past President Benj. D. Fuller, chairman of the committee.

REPORT OF CHANGES IN BY-LAWS, read by Vice-President A. B. Root, Jr.

REPORT OF THE COMMITTEE ON SPECIFICATIONS FOR GRAY IRON CASTINGS, read by Jesse L. Jones, chairman of the committee.

CONFERRING HONORARY MEMBERSHIP ON PRESIDENT L. W. OLSON.

The presidential address and the report of the secretary-treasurer are printed elsewhere in this volume.

The report of the nominating committee recorded the election of the following officers and directors:

A. B. Root, Jr., as President to serve one year.
S. W. Utley as Vice-President, to serve one year.

Directors to serve three years:

Fred A. Erb, Detroit, Mich.
C. E. Hoyt, Chicago, Ill.
Jesse L. Jones, Pittsburgh, Pa.
L. W. Olson, Mansfield, O.
H. S. Simpson, Chicago, Ill.

The report was accepted as read.

The resolutions committee which follows were unanimously approved as read:

From several important and attractive cities, the American Foundrymen's Association selected the city of Syracuse for its twenty-ninth annual meeting. The interest which the people in this thriving and enterprising city, with its growing industrial prosperity, manifested in the Association's affairs, and the delightful hospitality which they extended to its members have made a marked and edifying impression on the recipients. The memory of these pleasures will be lasting; they should have an acknowledgment of approvement.

THEREFORE, BE IT RESOLVED, that the American Foundrymen's Association present to the estimable people of Syracuse, to the manufacturers, to the Metal Trade Association, to the Foundry Association, and to the Chamber of Commerce, its appreciation of the cordial hospitality given its members and guests. To the men and women composing the various local committees who were untiring in their efforts to make the visit enjoyable, the association offers special thanks. Further, to the hotel and management, to the authorities of the State Fair Grounds, and to all other individuals who contributed to the comfort and entertainment of its members and guests in attendance at this convention, it is, indeed, deeply thankful.

Technical Papers

Each year with the advancement of scientific work that is required in the manufacturing of castings, the papers offered by technical specialists become more and more varied. This year the technical treatises and committee reports show important prog-

ress in the direction of perfecting casting processes. The work of the many research committees and what it has accomplished within the last few years, is strongly commended. The magnificent program presented this week was filled with the contributions of many authorities in foundry work. The association is sincerely appreciative of the efforts of these scientific experts who have been working in research laboratories, and of those men who individually contributed their experience in a practical way that others might benefit through their knowledge.

To all these authorities, committee workers, and special scientists in the casting industry of the world, the American Foundrymen's Association acknowledges its indebtedness for their work.

Exhibits

The exhibits of foundry equipment and supplies, which have been conducted concurrently at several conventions, show so much improvement in the American industry that the progress made this year among casting manufacturers is something that can hardly be measured. The improvement in machinery and methods of operation has been very scientifically and practically demonstrated. This year the number and quality of exhibits compare quite favorably with the best had at any time. To the manufacturers and exhibitors the American Foundrymen's Association feels deeply indebted.

Apprenticeship Training

For a number of years the American Foundrymen's Association and all American manufacturers have been confronted with the problem of supplying skilled mechanics, which at the present time is very inadequately done. The policy of the country, as expressed in its laws, is curtailing the development in this case, whereas, the skilled mechanic is needed in the extension of industry.

Apprentice training not only in the foundry industries, but in other industries of the United States, has become such a problem that "he who runs must read." The apprentice must study and work simultaneously. Some schools are offering excellent apprentice training and should be encouraged by the manufacturers. The

vocational schools at Milwaukee and the public schools of the country, especially in the state of New York, in so far as they carry on a vocational educational program, should be noticed.

THEREFORE, BE IT RESOLVED, that the American Foundrymen's Association co-operate in this movement of training apprentices, that its members employ the methods pursued by the school in training foundry apprentices, such as those used in Milwaukee, and that they endeavor to establish such schools in their respective localities, by working with the local industrial committee and the public school authorities.

Awards

Through the wisdom and generosity of certain donors who wished to encourage those who have contributed largely to the scientific and practical work in the advancement of the foundry industry, several awards have been made. The association commends the action of the Board of Awards in placing these honors. Their proper bestowal is one way to recognize ability and to awaken enthusiasm.

THEREFORE BE IT RESOLVED, that the committee receive the thanks of the association for their work, and that the recipients of the awards have its congratulations and appreciation for the efforts they have put forth in building up the foundry industry both scientifically and commercially.

The Association

This Association and its untiring executive organization, whose only compensation is the joy of increased success of the leading body of the foundry industries of the world, have done a tremendous work in the causes for which they labor. The men constituting the executive staff especially, in their zeal, have made this possible. Their co-workers knowing that there is so much in life that can be appreciated although not expressed, wish to recognize here how generously the staff has given of its time to the conduct of the affairs of the Association, and how faithfully and efficiently it has guarded its resources. The degree of conservation that it has used has been beyond the equivalent used by individual members in managing their private affairs. Therefore,

the Association expresses to its retiring President, W. L. Olson, to the Vice President, A. B. Root, and to the Board of Directors its great appreciation of their efforts.

Resolution respectfully submitted by

Resolutions Committee

C. B. CONNELLEY, *Chairman.*
L. L. ANTHES.

The report of the judges of the Obermayer award contest conferred the 1925 S. Obermayer Prize of the American Foundrymen's Association on H. W. Dietert and W. M. Myler, Jr., both of the engineering department of the United States Radiator Corporation, Detroit, Mich. The report read as follows:

"The committee assigned the duty of deciding the winner of the 1925 Obermayer Prize, carefully examined the devices, drawing, and prints submitted in this contest. The entries were five in number and we have unanimously decided in favor of the Continuous Temperature Recording Device submitted by H. W. Dietert and W. M. Myler, Jr., of the U. S. Radiator Corporation of Detroit.

Respectfully submitted.

B. D. FULLER, *Chairman.*
W. W. CHENEY, JR.
W. DOSEY.
A. E. WELLS.

The report was approved and H. W. Dietert was presented with the prize.

The changes in the by-laws are recorded in the report of the secretary printed elsewhere in this volume.

The report of the chairman of the committee on Specifications for Gray Iron Castings asked approval of the following resolution:

"Resolved, that this meeting refer to the Board of Directors of the American Foundrymen's Association the recommmending by the American Foundrymen's Association of a bar to be known as the International Test Bar, measuring 1.2 inches in diameter, 18 inches between supports, and cast in accordance with A. F. A. standard practice, physical characteristics of the bar to determine properties of the molten iron in the ladle.

"Be it further resolved, that nothing in this motion is to militate against the use by the British of three bars of varying diameter, or by the French of the Fremont-Portevin Test for judging the qualities of gray iron castings."

This resolution was unanimously approved for consideration by the Board of Directors.

The resolution submitted on behalf of the Board of Directors conferring honorary membership on the retiring president, L. W. Olson, was unanimously approved.

Session No. 13—Foundry Sand
Wednesday, Oct. 7, 2:00 p. m.

W. M. Saunders, chairman of Joint Commitee on Molding Sand Research, in the chair with R. F. Harrington as associate chairman.

The committee reports and papers presented were:

REPORT OF CHAIRMAN OF JOINT COMMITTEE ON MOLDING SAND RESEARCH, presented by W. M. Saunders.

REPORT OF SUB-COMMITTEE ON TESTING FOUNDRY SAND. In the absence of the chairman of the sub-committee, the report was read by W. M. Saunders.

REPORT OF SUB-COMMITTEE ON GRADING FOUNDRY SANDS, presented by A. A. Grubb, chairman of the sub-committee on grading.

REPORT OF SUB-COMMITTEE ON CONSERVATION AND RECLAMATION OF FOUNDRY SANDS, presented by R. F. Harrington, chairman of the sub-committee on conservation and reclamation.

REPORT OF SUB-COMMITTEE ON GEOLOGICAL SURVEY, in the absence of the chairman of the sub-committee, the report was read by W. M. Saunders.

SOME EXAMPLES OF RELATION BETWEEN THE FORMATION OF SAND DEPOSITS AND THEIR PHYSICAL CHARACTER, by D. W. Trainer, Geology Department, Cornell University, Ithaca, New York—presented by the author.

TESTING APPARATUS, by T. S. Adams, Cornell University, Ithaca, New York—read by title.

AN INVESTIGATION OF OHIO MOLDING SANDS, by P. Willard Crane, Cincinnati Resource Survey, Cincinnati, O.—presented by the author.

A METHOD OF TREATING AND HANDLING SAND, by Max Sklovsky, Deere & Company, Moline, Illinois—presented by the author.

The reports of the committees were approved as read and accepted as progress reports.

Session No. 14—Malleable Cast Iron
Thursday, October 8, 10:00 a. m.

Enrique Touceda in the chair with F. L. Wolf as associate chairman.

The following papers and one committee report were read and discussed:

WAGE INCENTIVES—GROUP BONUS PLANS, by B. R. Mayne, Saginaw Malleable Iron Company, Saginaw, Michigan. In the absence of the author, this paper was read by R. E. Kennedy.

ONE OF THE CAUSES OF VARIATION IN RATES OF GRAPHITIZATION OF WHITE CAST IRON, by Anson Hayes, and H. E. Flanders, Iowa State College, Ames, Iowa—presented by A. Hayes.

THE CATALYSIS OF THE GRAPHITIZATION OF WHITE CAST IRON BY THE USE OF CARBON MONOXIDE CARBON DIOXIDE MIXTURES WHEN APPLIED UNDER PRESSURE, by Anson Hayes and G. C. Scott, Iowa State College, Ames, Iowa—presented by A. Hayes.

CHEMICAL ELEMENTS INHIBITING GRAPHITIZATION, by H. A. Schwartz and G. M. Guiler, National Malleable and Steel Casting Company, Cleveland, O.—read by title.

A CONSIDERATION OF THE ANNEALING OPERATION IN A MALLEABLE FOUNDRY, by C. J. McNamara and C. H. Lorig, The Stowell Company, Milwaukee, Wisconsin.

REPORT OF COMMITTEE ON SPECIFICATIONS FOR MALLEABLE CASTINGS, presented by E. Touceda, chairman of the committee.

THE EFFECT OF SOME MODIFICATIONS OF A RAPID ANNEALING METHOD ON THE PHYSICAL PROPERTIES OF MALLEABLE IRON, by Anson Hayes, E. L. Henderson and G. R. Bessmer, Iowa State College, Ames, Iowa—presented by A. Hayes.

The report of the committee on specifications of malleable cast iron was approved as read.

Session No. 15—Metallurgy of Cast Iron
Thursday, October 8, 10:00 a. m.

Vice-President A. B. Root, Jr., in the chair.

The three papers presented at this meeting were:

NICKEL AND NICKEL-CHROMIUM IN CAST IRON, by T. H. Wickenden and J. S. Vanick, International Nickel Company, Bayonne, N. J.—presented by T. H. Wickenden.

THE OXYGEN CONTENT OF COKE AND CHARCOAL CAST IRON, by James R. Eckman and Louis Jordan, U. S. Bureau of Standards, Washington, D. C., and W. E. Jominy, University of Michigan, Ann Arbor, Michigan—presented by Dr. J. R. Eckman.

INFLUENCE OF PHOSPHOROUS ON THE TOTAL CARBON CONTENT OF GRAY IRON, by James T. MacKenzie, The American Cast Iron Pipe Company, Birmingham, Alabama—presented by the author.

Session No. 16—Sand Control
Thursday, October 8, 2:00 p. m.

Past President R. A. Bull in the chair with A. A. Grubb as associate chairman.

The papers read and discussed were:

MOLDING SAND CONTROL IN THE FOUNDRY, by H. W. Dietert and W. M. Myler, Jr., U. S. Radiator Corporation, Detroit, Michigan—presented by H. W. Dietert.

THE LIFE OF MOLDING SANDS, by C. M. Nevin, Cornell University, Ithaca, New York—presented by the author.

TESTING CORE SAND MIXTURES, by A. A. Grubb, Ohio Brass Co., Mansfield, Ohio—presented by the author.

METHOD OF TESTING CORE SANDS, by J. Fletcher Harper and W. J. Stevenson, the Allis-Chalmers Mfg. Co., Milwaukee, Wisconsin—presented by J. F. Harper.

The following resolution was unanimously approved:

In recognition of the hearty cooperation given the Joint Committee on Molding Sand Research by several educational institutions, government bureaus and state departments, the persons attending on October 8, 1925, a molding sand session of the

annual convention conducted by the American Foundrymen's Association, wish the following to be recorded as indicating the viewpoint of those present at the said session:

1. The assistance of non-commercial, scientific institutions and organizations has been and should continue to be very helpful to makers and users of all kinds of castings.

2. The help given the foundry industry by institutions and organizations as above described presents an illustration of what seems to us to be a wise and consistent policy followed for the advancement of industrial progress.

3. For the cooperation given the foundry and related industries by bodies and individuals not commercially connected with the said industries, those persons who are so connected are warmly appreciative.

Session No. 17—Gray Iron Foundry Practice
Friday, October 9, 10:00 a. m.

W. J. Kihn in the chair.

The following papers were read and extensively discussed:

SUPER-HEATING IRON IN THE CUPOLA, by S. J. Felton, Ohio Mechanics Institute, Cincinnati, Ohio, presented by the author.

EFFECT PRODUCED BY CHANGING SIZE OF CUPOLA TUYERES by J. Grennan, University of Michigan, Ann Arbor, Michigan—presented by the author.

QUALITY OF CORE OILS, by H. L. Campbell, University of Michigan, Ann Arbor, Michigan—presented by the author.

DESULPHURIZATION OF FERROUS METALS, by G. A. Drysdale, Metals Improvement Company, Cleveland, Ohio—presented by the author.

Proceedings of 1925 Convention Banquet

The annual banquet of the association in 1925 was held at the Hotel Syracuse, Syracuse, N. Y., October 8. President L. W. Olson presided during the presentation of the Seaman and MacFadden Gold Medals after which he turned the meeting over to W. M. Barr, President of the National Founders' Association, who acted as toastmaster.

President Olson after introducing the new officers of the association and distinguished overseas visitors, read the following cablegrams of greetings from various overseas foundrymen's associations:

"President of the American Foundrymen's Association:

Members of the Institute of British Foundrymen send cordial greetings on occasion of your twenty-ninth convention."

(Signed) Cameron, President.

"French Technical Foundry Association sends to American colleagues cordial regards and best wishes for success of congress and prosperity of American Foundrymen's Association."

(Signed) Ramas, President.

"Belgian Foundrymens Association addresses best wishes for success of your meeting."

(Signed) Masson, President.

After the reading of these messages, President Olson called upon Past President Benjamin D. Fuller to present the Joseph S. Seaman Gold Medal to Dr. Richard Moldenke.

PAST PRESIDENT BENJAMIN D. FULLER: *Mr. President, Ladies, and Gentlemen, and Dr. Moldenke:* Some few years back four big-hearted men, charter members of the American Foundrymen's Association, each presented the association with $5,000.00, the earnings from which were to be used in awarding medals for work of special merit benefiting the foundry industry.

This evening I have been assigned a very pleasant duty—that of presenting the first medal of award for distinguished serv-

ice, made possible through the generosity of our departed friend and past president, dear old "Daddy Seaman."

Last year Past President Howell, during an address, said that Daddy Seaman's character typified kindliness; a happy saying, for to those of us who knew him well the mere mention of Daddy's name causes a glow of kindly warmth to envelop our hearts. And how happy it would make the donor of this fund to know that the very first medal struck was to go to an old friend and co-worker, Dr. Moldenke. For these two men, the donor and the recipient, worked side by side for the American Foundrymen's Association when it was young and weak, nourished and guarded it until it was able to stand out and occupy a position commanding the attention and respect of the entire industrial world.

Dr. Moldenke was born in Watertown in the state of Wisconsin on November 1, 1864. Early in life his father, a Lutheran minister, removed to New York City. Here the Doctor received his early education in Columbia Grammar School and later in Columbia University, where he was graduated, an engineer from the school of mines. After two years as an engineer he returned to Columbia as an instructor where in a short time he received the degree of Doctor of Philosophy. This occurred during the year 1887, following which he was engaged in making geographic surveys as a member of the United States Coast and Geodetic Survey. In 1889 the doctor was called to the Michigan School of Mines where he organized the department of mechanical and electrical engineering. Leaving this activity after one year, Dr. Moldenke first became connected with the foundry industry as a metallurgist for the McConway and Torley company of Pittsburgh. Because of his intense interest in the work of original research he soon became well known. I can well remember when, as a general foreman in the iron foundries of the Westinghouse Electric and Manufacturing Company of Pittsburgh, I would take my troublesome problems to the doctor at the McConway and Torley laboratory, always to be benefitted by the visit.

In these early days he did much to "shake up" the minds of what I might term the "fundamentalists" of the foundry. Malleable iron, in those days, was not certified. It was not the

reliable product of today and the doctor's service to his employers proved to be of much benefit.

In 1897 Dr. Moldenke joined the Pittsburgh Foundrymen's Association and shortly after became a member of the American Foundrymen's Association, making the acquaintance of and becoming associated with such men as Thomas D. West, A. E. Outerbridge, W. J. Keep, E. H. Putnam, W. G. Scott and other pioneers in the investigation and broadcasting of foundry knowledge. About this time I had the opportunity of helping the doctor in his work by following out his instructions in casting a set of test bars in dry sand and another in green sand, the bars to be used in the preparation of standardized drillings for laboratory work.

In 1899 Dr. Moldenke took a prominent part in the organization of the Pennsylvania Malleable Company of Pittsburgh. Associated with him in this work was Mr. Stupekoff, well known for his work in the manufacture of pyrometers. The doctor acted as superintendent of this establishment until family considerations made it necessary that he resign to give his time to private interests.

At this time Dr. Moldenke was elected secretary of the American Foundrymen's Association, taking up the duties of this office in 1900. For fourteen years he served this body as secretary, seeing and actively assisting in the growth of this great association until from a small group it became recognized as one of the leading technical organizations of the world. The doctor's influence and the influence of the A. F. A. contributed much to the formation of similar associations and societies in Europe. Always giving, he became wealthy in acquired knowledge, for as John Howe Hall said last year at Milwaukee, "He who gives of his store freely, receives much in return." He originated and followed through investigations of much value. His cupola study revised old methods and resulted in economic operation and improved production. His study of coke, just as thorough and far-reaching, led to an investigation of this fuel conducted during the St. Louis Exposition. His work in this country and his prominent connection with the A. F. A. led to his being called to serve on international committees of investigation. His writings and

contributions to foundry literature have been most prolific, among which are his text-book, "Principles of Iron Founding," a book on malleable iron, many pamphlets, articles and treatises on a wide range of foundry subjects and materials. Recently in addition to his technical work, Dr. Moldenke has acted in an advisory capacity to foundries at home and abroad, to such large manufacturing concerns as the Bethlehem Steel Company and the Corn Products Refining Company. He has occupied an appointive position with the Bureau of Mines and received other like honors from government and state, is an honorary member of The American Foundrymen's Association, Institute of British Foundrymen, The Pittsburgh, New England and Newark Foundrymen's associations, has been vice-president of the American Society for Testing Materials, holds an active membership in the American Institute of Mining Engineers, The American Society of Mechanical Engineers, The American Electro-Chemical society, British Iron and Steel Institute, and German Varien Deutscher Eisenhuttenleute. His home is in Watchung, N. J., where he has established an experimental foundry, cupola and all, within the walls of the "Castle."

And now, Dr. Moldenke, will you arise to accept from the American Foundrymen's Association this, the first Seaman medal of award, to be granted any man;—this in honor of your untiring zeal and your valuable contributions to the industry. May God grant you many years of usefulness.

DR. RICHARD MOLDENKE: *Mr. President, Mr. Fuller, My Friends of the American Foundrymen's Association, Ladies and Gentlemen:* Eighteen years ago when you honored me with the presentation of a wonderful gift at the Philadelphia convention the surprise was so great that I could not express myself in words. This time you gave me a little notice and hence I have had time to make a reply.

You cannot imagine with what feelings of gratitude I heard about this coming presentation. As I stand here tonight there comes to my mind a visit last spring, with my good wife, to the famous park of the Rosenborg Castle in Copenhagen. Pausing in front of the statue of Hans Christian Anderson, of whom you all know, there came to my mind one of his fairy tales which is

not often read, called The Bell. The son of the king hears pealing in the distance a mysterious bell. He searches through the forest, going westward, further and further, striving to find a bell that is ringing. As he passes out of the forest and finally gets towards the ocean, at the end of all land, he catches the last rays of the sun going down, beyond, the golden rays, the warm rays. Then he hears the sound of the mysterious secret bell, and listens to the happy chorus of the spirits floating about it, to the strains of a joyous hallelujah. Tonight as I stand here with my feet definitely facing westward, for I am no longer young, my life is brightened by the golden rays of this beautiful present; and the generous warmth of your wonderful friendly feeling toward me as I have reached the end of a long and, I hope, useful but a very stormy career, and I assure you that I appreciate all this wonder fully.

"Daddy" Seaman, yes, a wonderful man, you all know him as one of nature's noblemen. A fine, sturdy spirit, clean, magnificent, always reliable in any emergency, the Nestor of the Foundrymen of America. He and I were friends, and I recall the first time that I met him, and it was in this way. . Whenever I, in my younger days was locating in a new place, the first thing I did was to connect myself with my church. So locating in Pittsburgh, I went down to the First Lutheran Church there, and the first man I was introduced to was Mr. Seaman. From that time on—in 1890—we became friends, and I was received in his family.

Almost a year later, when I went to New York City to my father's church and married my blessed little wife, she was received as I was in the bosom of Mr. Seaman's family. Later on our children came. The two oldest were little girls, and when at one time we lived where the back yards of the two houses came together, they often visited "Daddy" Seaman and sat on his knee and knew him as "Uncle Seaman." So there was friendship between us and it remained thus until he died.

While I was in Pittsburgh I was sometimes of real help to Mr. Seaman when he had difficulties in roll making, and there we got more particularly interested in this question of oxygen in cast

iron, because there I saw the serious effect of burning iron in his large furnaces. So I was able to help him a little bit and repay the friendship he gave me, and later on he actually offered me a partnership in his business. Had I been able to swing that very large proposition at that time I might today be very wealthy. Very often when I was discouraged and tired out from arduous work I would go to see Mr. Seaman and always found encouragement which did me a lot of good. "Daddy" Seaman will be remembered by all who knew him and his princely gift to the association, resulting in this medal will mean that he will remain known hereafter.

I do not wish to bore you, but I thought you might be interested in something a little more personal. As I look back over a long life of activity and perhaps some results that have been good to the foundry, I have been thinking of what instruments alike have been involved. What has specially contributed to my being able to do the little things I have for the foundry. And in the last analysis, I cannot help but feel that much came from the fact that I had very excellent parents, to whom I give the highest tribute.

Success, especially in the foundry, the technical part of it, is based upon preparation, research, investigation, development. It must have a sound basis of fact; it must have a wide range of information. And there I thank my father because he put me to school when I was three years old, and I have been to school ever since. I am just past sixty; that means fifty-seven years of school, and I will stay there as long as I live. There began my training which was shaped by him in two directions; first as an old world school man of education, a doctor of philosophy himself and a clergyman of high repute, he was particular that I should study the classics, and particularly history. Now, history I have always studied from the standpoint of the biographies of the great men of their time. That perhaps is the reason why I am familiar with world conditions, and in my political life it has served me wonderfully. So here was the foundation of a cultural and rather broad life which helped me greatly in looking at foundry problems from perhaps a larger viewpoint than the immediate returns. That is one angle.

Now the other angle was mathematics. Here I was right on the dot from early mental arithmetic until way up into university calculus. This was the groundwork of a logical mode of thinking, and our young men coming into foundry life would do well to use mathematics as the touchstone for training in order to think logically. They will find the benefit in their subsequent work.

Then later on as I entered the school of mines of Columbia University, and got into scientific training, my desire always was to go into applied science rather than pure science. I liked chemistry, metallurgy, and the painstaking investigation of little things. It is strange how those things shape your daily life. It meant that I soon got into the habit of making collections—I have a very fine one of minerals gathered personally in many parts of the world. But at that time I was collecting beetles, mosses, seaweeds, and the like. The consequence was that I was able, very soon, to see the little things where other people missed them. And it enabled me to run many a series of experiments and get wonderful information out of them which other men would pass by. It also got me into acquaintance with Thomas D. West, who was one of the best foundrymen that ever lived.

Another thing has had a marked effect on my life and its achievements, and that goes back a little more personally to my father. He was a Lutheran clergyman and was sent to the United States in 1861 to Wisconsin, Michigan and Minnesota, as a missionary among the early settlers who came from Prussia. He was sent by the church government of Prussia to collect them into churches and help them in their spiritual welfare, and in doing so at that time he became one of the pioneers of Wisconsin, and I was born in Watertown in that State.

You can imagine what it meant for my mother, who came from a noble house in Germany, to go into a log cabin in Wisconsin, right out in the primeval forest with the Indians. Once in wartime my father had to come back through that country in the midst of the terrible massacres that occurred then. Fortunately, he wore his church vestments and when he met the Indians who were carrying bloody scalps, they let him pass because he was a "medicine man."

It was his success in the West which caused the Prussian Government to call him back to take care of a parish containing 11,000 souls, of whom 3,000 were Germans and 8,000 were Poles. He returned from the United States, however, with ideas of freedom of thought and the first thing he started was a movement to separate church and state. He tackled that problem single handed in Prussia until he could not fight Frederick IV any more

American Foundrymen's Association
Through its Board of Directors
Acting upon the recommendation of the Board of Awards
has awarded
THE JOSEPH S. SEAMAN GOLD MEDAL
TO
Doctor Richard Moldenke
In recognition of his contributions to the Foundry Industry.
Annual Convention, Syracuse, New York, October 8, 1925.

AWARD CERTIFICATE PRESENTED TO DOCTOR RICHARD MOLDENKE, WITH THE JOSEPH S. SEAMAN GOLD MEDAL.

and had to leave. The World War has finally accomplished that separation of church and state in Germany.

My first recollection as a litttle child was my father's farewell sermon in that East Prussian church. I remember the soldiers in the church, and I remember the Polish farmers with their pitchforks in the church to defend my father against possible arrest. That meant doing something to advocate the American idea of freedom over there. It is that desire for freedom which

came to us that in later life made me feel that I would not accept anything that I was not satisfied to be actually so.

As I grew older and went to the University, my father took particular care of my physical well being. I was very much straighter when I was younger than I am now, and I did much in the way of physical exercise. One day when I was at Columbia, he said, "Richard, some day you may have to go into battle, and I want you able to care for yourself;" so he got a couple of rapiers and from that time on he taught me to fence, not only with the right hand but with the left, and that gave me one thing that had a decisive effect on my after life, quick thinking and doing the right thing at the right moment. It helped me afterwards in court cases when called as an expert. I have never as yet known any lawyer on the other side able to corner me.

My father thought the sword would remain the weapon of the future, and yet it has practically disappeared. I remember in Pittsburgh when our troops marched out to go to the front in the Spanish-American war, I was so ashamed that I could not go and fight for our country that I did not go to see the troops go out. I will say, though, that in the last war my son saved the honor of the family by enlisting before he was drafted. My father afterward became a very prominent man in our church, as president of the general council of the Lutheran Church in America, and left a revered name behind him.

I have helped in the revolution of the foundry; I have seen the changes as they came along; I took part in them; I met and compared notes with all the prominent investigators here and abroad, and the tendencies I have observed have been toward specialization, specialization all the time. The consequence is that the gray iron foundry, though becoming better, is going backward more than it should. I want to ask you to do all you can for research, for investigation, to make the work done in our foundries more exact, to produce constantly better material.

The future is going to bring us some big changes. I can see it in the meetings we have in the convention. The question of sand development is pointing to a synthetic sand. The question of finishing mold surfaces and making castings by machinery all

through to take care of labor scarcity wants to be watched and carried on further all the time.

Association work must be spread more, it must become more tolerant, more altruistic; we must not let selfish interests stop the spread of information, and we will thus find that the world will advance as it should. So our young men will take up the work that we older men will have to leave, and we can only stand by with our counsel and advice. Keep up the good work, and let the young men of today go on with it and pass it along to their successors. Now I want to thank you again for this wonderful gift which I will cherish and leave to my children; and I hope that my remaining years may still be devoted to helping to advance the foundry industry.

PRESIDENT OLSON: The presentation of the W. H. MacFadden medal will be made by Past President G. H. Clamer.

PAST PRESIDENT CLAMER: *Mr. President, Members of the American Foundrymen's Association, Ladies and Gentlemen:* As you have heard, through the generosity of four charter members and past officers, our association has been richly endowed with funds for the awarding of medals and for other purposes intended to encourage and stimulate meritorious effort in the industry of making metal castings. The donors of these endowment funds were so unselfish and so liberal minded that they placed these funds practically without restrictions in the hands of our association. The Board of Awards is the body within the association in whose custody the funds are placed, and upon whose recommendation, with the approval of the Board of Directors, the interest on these funds is either applied for the awarding of medals or to conduct research work which promotes the objects of the association, or to engage the services of such persons as may be selected by the Board of Awards to expound at its annual convention technical subjects in which the association is interested.

The donors have stated that it is their desire that an award, prize, medal or scholarship shall be conferred each year, if feasible, upon some person who shall, by his individual effort, have achieved very noteworthy results toward the attainment of those objects for which the Association was formed. The medals

established have been named after the donors of the endowment funds as follows:

John A. Penton Medal.
Joseph S. Seaman Medal.
J. H. Whiting Medal.
William H. MacFadden Medal.

By the wise provision that medals shall be awarded only at such times as in the judgment of the Board of Awards some individual has, by his own efforts, merited an award will for all time keep these medals upon a high standard in respect to the accomplishment for which they are awarded.

The Board of Awards consists of the last seven living past presidents of the association; the board is self-perpetuating as each retiring president becomes a member, taking the place of the senior past president on the board. The junior past president, according to the provisions, shall be chairman. As junior past president, I have had during the past year the privilege and pleasure of serving on the board as chairman. I have found that the responsibility of the Board of Awards is great. I have also learned by experience that the duties conscientiously performed, as they must of necessity be by a board constituted as is ours, are quite arduous. This is occasioned by the fact that the work, or the accomplishments of each proposed candidate, must be thoroughly investigated in order to make an intelligent comparison of their respective merits.

At a meeting of the Board of Awards, June 18, 1923, the board recommended that if, at the 1924 Convention, a paper of outstanding merit be presented, the Wm. H. MacFadden Medal of the American Foundrymen's Association be given to the author in recognition of said contribution, presentation to be made at the 1925 convention of the association. At a meeting of the Board of Directors held the following day, the recommendation of the Board of Awards was unanimously approved. Following the Milwaukee convention, members of the papers committee were requested to review papers presented and submit a report for the guidance of the Board of Awards. A summary of this report was submitted, and with this report before it, the members of

the Board of Awards individually studied the papers, but it was found impossible to secure a majority vote in favor of making the MacFadden award to any author in recognition only of a paper submitted at the 1924 Convention.

The Board of Awards, having reached the conclusion that no paper of sufficiently outstanding merit was presented at the 1924 convention, to be recognized by the award of the MacFadden medal, decided to investigate the merits of workers in the non-ferrous foundry field. The John A. Penton medal was last year awarded to Enrique Touceda for his outstanding accomplishments in the improvement of malleabilized iron castings and the J. H. Whiting award to John Hall Howe for his signal accomplishments in the steel castings industry. This year without question or debate the board unanimously agreed upon Dr. Richard Moldenke as the logical recipient of the Joseph S. Seaman medal, for his great influence in stimulating the scientific study of foundry problems, and particularly because of the improvements in the art of producing gray iron castings, resulting from his investigations and studies. This left the only remaining field of the foundry industry without recognition, namely, the non-ferrous casting field. The voluminous work of Dr. Robert J. Anderson, particularly in connection with metallurgy of aluminum and aluminum alloys, and the production of aluminum castings, was brought to the attention of the Board of Awards.

Dr. Anderson is a relatively young man, but his publications, most of which have been based on personal investigations have been voluminous. Not only has Dr. Anderson a capacity for work, but it is evident that he could only have accomplished the great amount which he in his short life has accomplished, by applying his talents most strenuously. The question was raised by the board as to whether his publications were of a practical nature. The large manufacturers of aluminum castings were, therefore, consulted, and they replied in a very complimentary and in no uncertain way that Dr. Anderson's work and publications had been of great benefit to their industry. He is without doubt now recognized as an authority in the field of aluminum and aluminum alloys. He has carried out many investigations on various aspects of aluminum-alloy founding, such as scrap losses

and waste, blowholes and porosity, inclusions and cracks, on melting loss and foundry practice. The results of the majority of these investigations have been published in the proceedings of the American Foundrymen's Association and governmental papers.

Dr. Anderson has also carried out investigations and published his findings on the heat treatment of aluminum alloy castings, and on the radiography applying to such castings. He has also published results of investigations on the metallography, heat treatment and founding of brass, bronze and other copper alloys, together with investigations on the corrosion of metals and alloys. His recent book, "The Metallurgy of Aluminum and Aluminum-Alloys," published in 1925, has received an excellent reception both here and abroad as a standard text and reference book in its field. During the past summer I visited in Europe a number of prominent non-ferrous plants. I found Dr. Anderson's new book on their bookshelves. Dr. Anderson has contributed extensively to the technical sessions of the American Foundrymen's Association. In 1924, in collaboration with M. E. Boyd, he contributed the American Foundrymen's Association exchange paper for the Institute of British Foundrymen's convention of that year. He also, as co-author with Mr. Boyd, presented two creditable papers at the 1924 Convention of our association.

I have the honor, Dr. Anderson, to formally award to you, upon recommendation of the Board of Award and the unanimous approval of the Board of Directors, the William H. MacFadden Medal of the American Foundrymen's Association, for your contributions to the proceedings of our Association, and your scientific contributions to the aluminum casting art.

DR. ROBERT J. ANDERSON: *Mr. Chairman, Mr. Clamer, Ladies and Gentlemen:* The notification from our secretary, Mr. Hoyt, that I had been appointed as a recipient of the MacFadden medal came to me as a most unexpected but happy surprise. I appreciate in the highest degree the compliment this medal conveys and hasten to express my sincere thanks to the members of the Board of Awards for their consideration in awarding it to me. Thanks are also due the donor for his generosity in providing the medal. It is difficult to express properly my appre-

ciation of the many complimentary remarks which have been made about my work, but I am going to refrain from saying the usual things about my unworthiness, since this might well be construed as a reflection on the judgment of the Board of Awards.

Reference has been made to so-called distinguished work done by me. Now, I may say that no scientific man does his work, whatever it is, with the object of rendering distinguished service, but rather because he likes to do his job. Mr. Clamer, in his references to me, has betrayed my age, and really I feel more or less out of place among so many venerable and honorable members of our art and craft.

In view of the fact that this medal has been conferred mainly because of my work in the field of aluminum metallurgy, a word on that metal may not be out of place. The year 1925 happens to be the centennial of aluminum. The discovery of the metal is generally credited to F. Wöhler, under date of 1827, but there is various historical evidence that the metal had previously been prepared by Oersted in 1824 or 1825. As is well known, Sir Humphrey Davy, in 1806 made an alloy of aluminum and iron by the fusion of alumina and iron under reducing conditions, the resulting alloy being whiter than iron and certainly containing aluminum. In a communication to *Chemie et Industrie* this year, Matignon and Faurholt set the date of first preparation as 1825 by Oersted. Oersted first proposed to convert alumina into aluminum chloride and then reduce this with hydrogen, but failed. He then substituted potassium amalgam as a reducing agent instead of hydrogen and obtained a reduction, the results being published before the Danish Society of Sciences in the early part of 1825. A specimen of the metal obtained was shown at this time. The minutes of the society contain the record of this work.

Two years later, in 1827, Wöhler obtained aluminum by the reduction of the chloride with potassium alone. Wöhler had visited Oersted in Copenhagen and obtained certain information regarding the latter's work, and in 1827 he (Wöhler) published his results concerning aluminum. Matignon and Faurholt have just recently repeated the early experiments of both Oersted and Wöhler and find that aluminum can be obtained by the reduction of its chloride either with potassium or potassium amalgam. It

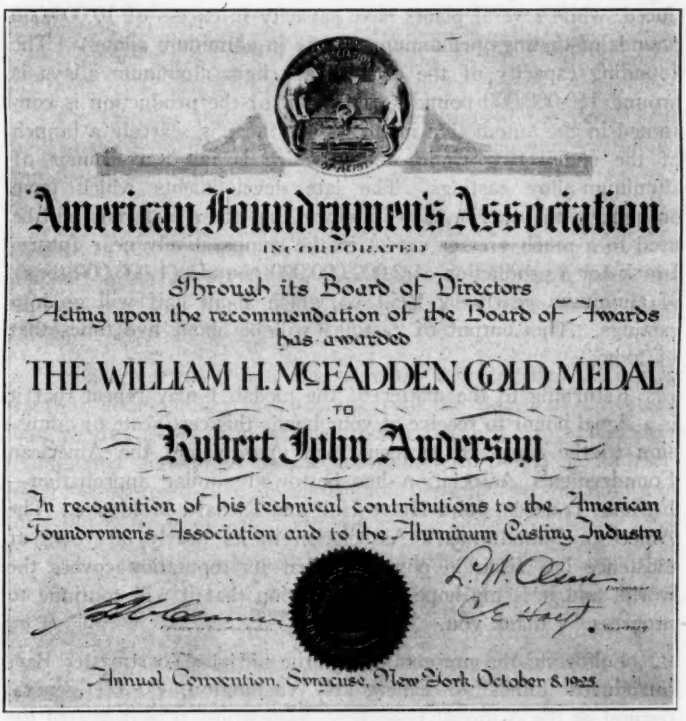
is, therefore, claimed that Oersted was the real first producer of aluminum and the metal is accordingly 100 years old this year.

It is a far cry from the laboratory trials of 1825 to the aluminum industry of today. The present production of metal is around 400,000,000 pounds per annum, and the price has dropped from around $90.00 per pound (in 1856) to a low price of around 19 cents (in 1914). The market price today is around 27 cents. The world's production of aluminum since 1900 has increased about 100 per cent every five-year period over the previous five-year period, and the metal is now fourth in tonnage among the non-ferrous metals, following lead, tin and zinc. By 1940, it is expected that the output will be second only to that of copper.

With regard to aluminum-alloy castings, only a few alloys, even 15 years ago, were considered suitable for structural purposes and then merely for unstressed members; at the present time a wide variety of aluminum-alloy castings is being produced and used in competition with brasses, bronzes, cast iron, and even alloy steels in engineering construction. Aluminum-alloy castings, as substitutes for cuprous or ferrous-alloy parts, may be given consideration by the constructing engineer for several reasons which make a direct appeal, viz. (1) low specific gravity (ranging from 2.6 to 3.0); (2) high specific tenacity—on a strength-weight basis light alloys in the cast and heat-treated condition are available, which are equivalent to steel having tensile strength of 180,000 pounds per square inch; and (3) cost—on a price-mass basis, a light alminum-alloy part may be cheaper than a cuprous-alloy part, despite the relatively high cost of aluminum on a pound basis.

The high specific tenacity (specific strength) of the light aluminum alloys is often overlooked. Consideration of these materials is often dismissed on the notion that "they are not strong enough." Is there any truth in this? If so, what is the evidence? The evidence is that an ordinary aluminum casting alloy having tensile strength of 20,000 pounds has more than double the specific tenacity of ordinary cast iron (21,000 pounds), is about equal in specific tenacity of cast monel metal (70,000 pounds), and cast steel (60,000 pounds). The specific tenacity,

as you know, denotes a quantity obtained by dividing the tensile strength of a given alloy in pounds (or tons) per square inch by the weight of a cubic inch in pounds; the quotient is the breaking load in pounds (or tons) of a bar of the material whose cross section is such as to make the weight of the bar 1 pound per inch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Annual Convention, Syracuse, New York, October 8, 1925.

AWARD CERTIFICATE PRESENTED TO DOCTOR R. J. ANDERSON, WITH THE WILLIAM H. McFADDEN GOLD MEDAL.

of length. The property may also be expressed as the simple ratio of strength to specific gravity. One could talk half the night without exhausting the demonstrated merits of aluminum alloys versus other constructional materials, but enough has been said to indicate their value and possibilities.

Turning for a moment to the situation in aluminum-alloy founding; prior to 1910 there was no exclusive aluminum-alloy foundry in the United States. The alloys were cast largely in connection with brass and then in small production. Today, there are some 2,500 foundries and departments of manufacturing plants, in this country, in which aluminum-alloy castings are produced, while several plants have capacity in excess of 10,000,000 pounds of castings per annum (solely in aluminum alloys). The founding capacity of the country for light aluminum alloys is around 150,000,000 pounds. The bulk of the production is consumed in the automotive industry, but there is scarcely a branch of the engineering trades today which is not a consumer of aluminum-alloy castings. The late developments which have brought forth superior alloys indicate that these materials will be used to a much greater extent in the comparatively near future. I look for a production of 2,000,000,000 pounds (1,000,000 tons) of aluminum yearly by 1950, of which about half will go into castings. This output of castings will be about five times that of today.

Returning to the matter of the medal, I may repeat that it is a signal honor to receive at your hands this certificate of admission to the ranks of eminent men upon whom the American Foundrymen's Association has bestowed similar approbation—Enrique Touceda, John Howe Hall and Richard Moldenke. The American Foundrymen's Association in its nearly 30 years of existence has risen in power so that its reputation covers the world, and it is my hope and conviction that it will continue to progress. I thank you.

Following the presentation of the medals, Toastmaster Barr introduced James A. Emery of Washington, D. C., general counsel of the National Founders' Association, who delivered the address of the evening.

Annual Report of the Board of Directors

To the Members of the American Foundrymen's Association, Inc.,
Gentlemen:

Meetings of the Board of Directors during the calendar year 1925 were held as follows:

On October 4 a regularly called meeting of the Board was held at the Syracuse Hotel, Syracuse, N. Y., immediately following the alumni dinner.

In calling the meeting to order President Olson requested all present to rise and stand in silent tribute to the memory of A. O. Backert, who had served the Association as secretary, president, and director, and whose death occurred at his home in Cleveland on April 24, 1925.

Following this tribute the secretary reported that Alfred E. Howell, acting under instructions from the Board of Directors, had written a beautiful tribute to Mr. Backert, which had been illuminated, signatured by the president, vice president, and secretary-treasurer, bound in leather and presented to the family of Mr. Backert.

The secretary announced that this tribute had been published in the June issue of the A. F. A. Bulletin, and would also appear in the Bound Volume of Transactions.

The awarding of the Joseph S. Seaman Gold Medal to Dr. Richard Moldenke, and the William H. McFadden Gold Medal to Dr. Robert John Anderson, in accordance with the recommendations of the Board of Awards, and approved by letter ballot of the Board of Directors, was ratified.

The report of the committee to consider revisions of the by-laws was received, and with certain changes approved, and the secretary was instructed to submit the proposed revisions to the members for approval by letter ballot.

It was announced that the committee on place and time of the 1926 convention had unanimously selected Detroit, and the week of September 27 as the date.

The Board unanimously voted to recommend to the members that L. W. Olson be made an honorary member upon retiring as president.

Mr. Howell presented to Major R. A. Bull an illuminated copy of resolutions which had been authorized by the Board of Directors. A copy of these resolutions appears in the minutes of this meeting.

The meeting adjourned to meet again on Wednesday, October 7.

At the adjourned meeting H. W. Dietert and Wm. M. Myler were awarded the S. Obermayer prize of the American Foundrymen's Association for their entry, A Continuous Iron Temperature Recording Device.

On December 8, at Detroit, the final meeting of the 1925 Board of Directors was held. Reports of the Secretary, Treasurer, Manager of Exhibits, and Committees, were received.

Acting upon the recommendation of the Finance Committee certain transfers or funds were authorized.

The Secretary reported that the result of the ballot to approve amendments to the by-laws was 548 affirmative; negative none. On motion it was voted to make the amendments effective January 1, 1926.

The Board approved the recommendations of the gray iron committee on an international test bar for the determination of properties of the molten iron in the ladle.

The result of the election of officers and directors at the annual meeting of the Association in Syracuse, N. Y., October 7, 1925, was read into the minutes.

Resolutions of appreciation of the faithful services of Directors Verne E. Minich and C. B. Connelley, were adopted.

The retiring president, L. W. Olson, declared the meeting of the old board adjourned, and President-elect A. B. Root, Jr., immediately convened the meeting of the new board.

The new board was organized by electing an executive secretary-treasurer, technical secretary, manager of exhibits, and executive committee.

The report of the finance committee on salaries and appropriations was adopted.

A plan for the election of four members of the 1926 Nominating Committee was approved. The board nominated eight members for the official ballot and provided for additional names proposed by members.

Plans for conducting the annual convention and exhibit were discussed and approved.

The appointment of a committee by the president, to consider place for the 1927 meeting was authorized, and to the executive committee was delegated power to determine the time and place of meeting if in their judgment it was found wise to make such a decision before another board meeting.

With this report we show full minutes of the meetings of the Board.

Respectfully submitted,

C. E. Hoyt, *Secretary-Treasurer*
For the Board of Directors.

Minutes of Meetings of Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION

AT

SYRACUSE, N. Y., OCTOBER 4, 1925

Following the alumni dinner at Hotel Syracuse, Sunday evening, October 4, a regularly called Board meeting was held with President L. W. Olson presiding. The following were present: Vice-President A. B. Root, Jr., Secretary C. E. Hoyt, Assistant Secretary R. E. Kennedy, Directors L. L. Anthes, G. H. Clamer, C. B. Connelley, Fred Erb, A. E. Hageboeck, T. S. Hammond, A. E. Howell, C. R. Messinger and V. E. Minich; Past Presidents R. A. Bull, B. D. Fuller and C. S. Koch, and Past Secretary Dr. Richard Moldenke.

In calling the meeting to order President Olson requested all present to rise and stand in silent tribute to the memory of A. O. Backert, who had served the Association as secretary, president, and director, and whose death occurred at his home in Cleveland on April 24, 1925.

Following this tribute the secretary reported that Alfred E. Howell, acting under instructions from the Board of Directors, had written a beautiful tribute to Mr. Backert, which had been illuminated, signatured by the president, vice-president and secretary-treasurer, bound in leather and presented to the family of Mr. Backert.

The secretary announced that this tribute had been published in the June issue of the A. F. A. Bulletin and would also appear in the bound volume of transactions.

On motion the reading of minutes of the last meeting of the board was waived.

APPOINTMENT OF JUDGES FOR OBERMAYER PRIZE

B. D. Fuller was appointed chairman of judges for the Obermayer Prize, with Professor A. E. Wells, Cornell University; Wm. H. Dosey, Carnegie Institute of Technology, and W. W. Cheney, Jr., Syracuse, as members of the committee. The committee was instructed to judge the entrees for the Obermayer Prize and submit a report to the Board at an adjourned meeting to be held Wednesday, October 7, at 1:15 p. m.

The chair appointed Alfred E. Howell as a committee of one to purchase a suitable prize to be presented to the winner of the Obermayer contest.

Report for the Board of Awards

The secretary reported that he had received from G. H. Clamer, chairman of the A. F. A. Board of Awards, a report recommending that the Joseph S. Seaman gold medal of the American Foundrymen's Association be presented to Dr. Richard Moldenke in recognition of his contributions to the advancement of the foundry industry, and to Dr. Robert John Anderson the William H. McFadden gold medal of the American Foundrymen's Association in recognition of his written contributions to this Association and to the aluminum casting industry.

The secretary reported further that, acting upon the instructions of President Olson, the recommendations of the Board of Awards had been submitted to the members of the Board of Directors for their approval by letter ballot, and that the result of said letter ballot was the unanimous approval by the directors of the recommendations of the Board of Awards, authorizing the presentation of the Joseph S. Seaman Medal to Dr. Richard Moldenke and the William H. McFadden Medal to Dr. Robert John Anderson, presentation to be made at the annual banquet of the Association, Thursday evening, October 8, 1925.

The secretary reported further that the medals had been ordered struck and engraved, and that certificates of award had been engrossed.

On motion it was ordered that the recommendations of the Board of Awards and the result of the letter ballot of the Board of Directors be entered into the minutes of this meeting as a matter of record.

Report of Committee on Revision of By-Laws

The secretary reported that at the last meeting of the Board of Directors, November 20, 1924, the report of the committee on revision of the By-Laws had been referred back and the committee continued, that this committee had redrafted the revisions, and that copies of these revisions had been mailed to each member of the Board of Directors and to each state and district membership committee chairman inviting comment.

The report of the committee was then submitted. It was moved and seconded that the report be accepted. A lengthy discussion followed. Expressions called for by the chair indicated that certain changes in the report were favored by a majority present, whereupon the mover of the motion to approve, with the consent of the second, withdrew his motion.

It was then moved that the chair appoint a committee of three to retire and prepare a revised report in accordance with suggestions offered. The chair named A. B. Root, Jr., R. A. Bull and T. S. Hammond, and following a brief intermission they brought in the following report, which was unanimously approved by the directors present, and the secretary was

instructed to submit the proposed amendments to the active and honorary members for letter ballot:

ARTICLE I (No change)

ARTICLE II

Membership

Section 1.—The membership of this Association shall consist of the following classes: Active, Junior and Honorary Members.

Section 2.—Any person, or group of persons as defined in this section, interested in the objects of this Association, may be elected as an Active Member. The membership privileges of a group shall be exercised by a designated individual belonging to the group.

Additional persons within and employed by or associated with such group may become active members as hereinafter provided.

A group of persons as referred to above shall be a corporation, a subsidiary of a corporation, a branch of a corporation, a company, a firm or partnership, an association or a society. A group, however, shall not be interpreted to mean more than one branch, unit or separate plant of the same organization.

Section 3.—Any person who is less than twenty-five years of age and is interested in the objects of this Association, may be elected as a Junior Member, but shall not have the right to vote or hold any elective office.

A Junior Member having reached the age of twenty-five years shall become an Active Member without election as such, and without payment of an entrance fee.

Section 4.—Any persons whose activities in the Foundry Industry, or any branch thereof, or whose services in connection with the objects of this Association make him pre-eminent among his fellows, may be elected to Honorary Membership.

Section 5.—Election to Active and Junior Membership shall be by a three-fourths vote of all the Directors. All applications for membership shall be made in writing to the Executive Secretary, by whom they shall be referred to the Directors.

Section 6.—Election to Honorary Membership shall be by a three-fourths vote of the members of the Association present at a regular meeting, voting upon a recommendation of the Board that such Honorary Membership be conferred.

Section 7.—Each Active and Honorary Member shall be entitled gratis to one copy of every publication of the Association which such member shall elect to receive, in a manner to be prescribed by the Board of Directors.

Section 8.—Resignations may be submitted in writing to the Executive Secretary. The resignation of a member whose dues are in arrears shall not be accepted.

Section 9.—The membership of any person, firm or organization may be suspended or terminated by a three-fourths vote of all the Directors. In such case remission of proper proportion of dues paid in advance shall be made.

ARITCLE III

Officers and Directors

Section 1.—The officers shall consist of a President and a Vice-President, elected annually from and by the active and honorary members; and an Executive Secretary, a Treasurer, a Technical Secretary, an Assistant Secretary, and a Manager of Exhibits, all of whom shall be elected annually, when practicable, by the Board of Directors. Any offices, except those of President, and Vice-President, in the discretion of the Board of Directors, may be combined.

Section 2.—The Board of Directors shall consist of the President, the Vice-President, and fifteen other Directors, elected by and from the active and honorary members.

Sections 3, 4 and 5.—No change.

ARTICLE IV (No change)

ARTICLE V

Duties of Officers

Sections 1 and 2.—No change.

Section 3.—Insert the word "Executive" before "Secretary."

Section 4.—No change.

Section 5.—The duties of all officers or employees of the Association, not defined in these By-Laws, shall be as prescribed by the Board of Directors.

Section 6.—Same as present Section 5.

Section 7.—Same as present Section 6.

ARTICLE VI (No change)

ARTICLE VII

Salaries

Section 1.—The Board of Directors shall annually make provision for the salaries of officers, and compensations of all persons whose services to the Association justify such action. Information concerning all salaries and compensations paid shall be published annually in the Transactions.

ARTICLE VIII

Fees and Dues

Section 1.—The entrance fee for Active Members shall be $10.00. This fee shall be waived in the case of any individual elected to membership who is connected with or employed by a firm or group already holding Active Membership, and also for such persons as are actively engaged in educational pursuits not of a commercial character.

There shall be no entrance fee for Junior Members.

Entrance fee shall be submitted with the application for membership.

The Board of Directors may temporarily waive the requirements for entrance fee when in their judgment the best interests of the Association shall be served by so doing.

Section 2.—Dues for Active Members residing in the United States or Canada shall be $12.00 per annum, except that dues for additional persons as referred to in Article II, Section 2, and persons engaged in educational pursuits as referred to in Article VIII, Section 1, shall be $7.50 per annum.

Dues for Active Members residing in all other countries shall be $10.00 per annum.

Dues for Junior Members shall be $5.00 per annum.

Honorary Members shall not be required to pay dues.

All dues shall be payable in advance on the first day of January of each year. Any member whose dues are twelve months in arrears shall be declared delinquent and shall be dropped from the membership roll.

In recognition of long or special service, or for other justifiable reasons, the Board of Directors may, by a three-fourths vote, exempt any member from payment of dues and declare him a member for life.

Section 3.—Dues of new members shall be payable promptly upon notification of election to membership.

Section 4.—Entrance fees shall apply to continuous membership only, and those who allow their memberships to lapse for twelve months shall be required to pay the regular entrance fee upon resuming active membership.

ARTICLES IX, X, XI AND XII (No change)

ARTICLE XIII

Advisory Board

Section 1.—Omit the words "and all honorary members."

ARTICLES XIV, XV, XVI, XVII AND XVIII (No change)

Place for 1926 Meeting

G. H. Clamer announced that it was his pleasure to present, on behalf of the Philadelphia Foundrymen's Association, the City of Philadelphia, and the Sesqui-Centennial Committee, an invitation to hold the 1926 convention of the American Foundrymen's Association in the City of Philadelphia. The Secretary was instructed to acknowledge the invitation from the City of Philadelphia.

The Secretary reported that the committee appointed at the last meeting of the Board, with full authority to select a place and time for the 1925 convention, was also authorized to select a city and name the date for the 1926 convention, and that said committee had unanimously selected the City of Detroit as the place and the week of September 27th as the time for the thirtieth Annual Convention of the Association and the second International Foundrymen's Congress.

Time and Place of Annual Board Meeting

On motion it was decided to hold the annual meeting of the Board of Directors in the City of Detroit, Tuesday, December 8, 1925.

L. W. Olson Recommended for Honorary Membership

Mr. Root, addressing the Secretary, said it was his pleasure to move that the Board of Directors recommend that at the annual business meeting of this convention they confer upon retiring President L. W. Olson, at the expiration of his term of office, the title of Honorary Member of the American Foundrymen's Association, which motion was seconded by Mr. Connelley and unanimously adopted.

Presentation of Resolution to Major Bull

President Olson called upon Mr. Howell to present the resolution of appreciation to Major R. A. Bull authorized by the Board on the occasion of his retirement from the Board, after continuous service of fourteen years as Vice-President, President and Director. Mr. Howell read the resolution and then presented to Major Bull a beautifully illuminated copy. Mr. Howell appropriately referred to his constructive and loyal services, and in response Major Bull expressed his sincere appreciation of this formal acknowledgment and recognition of services rendered, and spoke feelingly of his association with members, particularly those who had served with him over the period of years during which he had been officially active.

Following is a copy of the resolution:

"This Appreciation of MAJOR ROBERT ALEXANDER BULL is by unanimous action of the Officers and Board of Directors of the AMERICAN FOUNDRYMEN'S ASSOCIATION.

"Such service as has been given this Association by Major Bull from 1911 to 1924 inclusive must not be terminated without an expression preserved in some form, which we hope may be a pleasure for him to keep as a lasting evidence of the esteem in which he is held by us.

"Elected to the Presidency at a critical period, he effected the change of the Association from a loosely knit one, to a chartered and incorporated institution.

"The many difficulties encountered and overcome are remembered by his associates, who fondly number him chief among a small coterie who started the Association on a career of enlarged service to the industry.

"It is a pleasure for us to recall and to record our appreciation of his multifarious services, his energy, his ability and his wisdom in counsel. We prize the affectionate regard which is the outgrowth of our contact with him and wish for him and his loved ones enduring happiness and prosperity.

"AMERICAN FOUNDRYMEN'S ASSOCIATION.

L. W. Olson, President.
A. B. Root, Jr., Vice-President.
C. E. Hoyt, Secretary."

November 21, 1924.

There being no further business, the chair declared the meeting of the board adjourned to meet at Association headquarters, State Fair Grounds, Wednesday, the 7th, at 1:15 p. m.

Respectfully submitted,

L. W. OLSON, President.
C. E. HOYT, Secretary.

MINUTES OF ADJOURNED MEETING OF THE BOARD OF DIRECTORS AMERICAN FOUNDRYMEN'S ASSOCIATION, AT SYRACUSE, N. Y., OCTOBER 4, 1925

The adjourned meeting of the Board of Directors was held at Association headquarters, State Fair Grounds, 1:15 p. m., Wednesday, October 7, for the purpose of receiving the report of the judges on the S. Obermayer Prize Contest.

B. D. Fuller, Chairman of the Judges, submitted the following report: "To the Board of Directors, American Foundrymen's Association.

"We, the undersigned committee appointed to act as judges of the 1925 Obermayer Prize Contest, recommend that the prize be given to H. W. Dietert and W. M. Myler, Jr., for their entry 'A Continuous Iron

Temperature Recording Device,' which was deemed most worthy of all the entries submitted."

Respectfully submitted,

(Signed) BENJ. D. FULLER, Chairman.
WILLIAM H. DOSEY.
A. E. WELLS.
W. W. CHENEY, JR.

On motion duly seconded, the report of the committee was accepted. The secretary reported that Mr. Howell, who had been appointed by the board as a committee of one to purchase a suitable prize, had secured a watch at a cost of $35.00, which he had had engraved with the wording "Obermayer Prize, 1925," with space for engraving the name of the one to whom the award was made, not having anticipated the possibility of the prize being awarded to two persons.

On motion duly seconded, the secretary was instructed to have the name of one of the winners engraved on the watch, and to purchase another watch or some other prize of equal value for the other winner.

President Olson announced that the meeting would take a recess until after the annual business meeting, when they would reconvene to hear a report from the Cost Committee.

Following the recess, the meeting of the board reconvened with President Olson, Vice-President Root, Directors Hammond, Hageboeck, Erb, Minich, Clamer, Connelley and Hoyt present.

Mr. Hageboeck, chairman of the A. F. A. Committee on Foundry Costs, made a report of the activities of the committee during the week at the booth in Grange Building and at the session held on Tuesday, which was addressed by E. T. Runge and W. J. Barrett of New York.

Mr. Hageboeck reported an unusual and most gratifying interest, with an attendance at the Cost Session of approximately 400. He said the committee felt that all this indicated a keen interest in the matter of costs on the part of the members of the A. F. A., and they would recommend that the board of directors authorize them to proceed with some plan that would capitalize the interest of the country. To this end they would recommend that some arrangement be made to retain an advisory accountant of the A. F. A., and that the A. F. A. lend its efforts to organizing groups in various sections of the country to study costs and install systems that would be especially adapted to the particular group.

It was the consensus of opinion of those present that it would not be wise for the Association at this time to recommend any particular accountant, but all were agreed that the work of the committee should be endorsed and that they should continue along the same lines, spreading

cost propaganda and encouraging foundrymen to take an active interest in this subject. To this end it was moved that the secretary be instructed to publish in pamphlet form the proceedings of the cost meeting, and that if possible these be mailed out with the next Quarterly Bulletin to members and offered for sale to non-members at a price to be determined.

The committee was requested to present to the next meeting of the board some plan for accomplishing the results they desired to obtain.

There being no further business, the meeting was declared adjourned.

L. W. Olson, President.
C. E. Hoyt, Secretary.

Approved December 8, 1925.

Minutes, Annual Meeting, Board of Directors, American Foundrymen's Association at Detroit, Mich., December 8, 1925

This meeting was called to order by President L. W. Olson at the Book-Cadillac Hotel, 10:00 a. m., Tuesday, December 8, 1925.

The following responded to roll call: President L. W. Olson, Vice-President A. B. Root, Jr., Directors L. L. Anthes, G. H. Clamer, C. B. Connelley, Fred Erb, A. E. Hageboeck, Alfred E. Howell, C. E. Hoyt, V. E. Minich and Wm. J. Nugent. Assistant Secretary R. E. Kennedy and Director-elect Jesse L. Jones were also present.

Reading of Minutes

Minutes of the meeting held at Syracuse, October 4th, were read and approved.

Report of Secretary

Secretary Hoyt read his annual report to the board. On motion the report as read was accepted and ordered filed.

Report of Manager of Exhibits

A report covering the Syracuse Exhibit was read by Manager Hoyt and on motion was accepted and ordered filed.

Report of Treasurer

Secretary-Treasurer Hoyt in submitting the treasurer's report stated that detailed statements showing receipts and disbursements for the eleven months, January 1 to November 31, had been submitted to the Finance Committee appointed by President Olson, who would submit a report. The treasurer then submitted a general statement showing condition of the Association's finances and gave estimated expenses and income to December 31, at which time the books of the Association would be audited and a report prepared for publishing in the bound volume.

On motion the report of the treasurer was accepted and ordered filed.

Report of Finance Committee

The chair announced that he had appointed as members of the Finance Committee A. B. Root, Jr., chairman, S. W. Utley, and H. S. Simpson.

The report submitted by Chairman Root gave as the estimated net gain in operations for the department of exhibits for the year ending December 31, 1925, $3,690.93, and the estimated cash balance, if all bills receivable were collected, as $7,209.85 less any authorized transfers of funds.

In making the report the chairman stated that at the last annual board meeting the directors had authorized the withdrawal of $2,500.00 for the reserve fund for research work, and inasmuch as this transfer had not been made, the committee recommended that in lieu of taking this sum from reserve the general technical fund be reimbursed from the exhibit department surplus to the amount of $2,500.00.

Assuming that the transfer of the sum of $2,500.00 is made, either from the reserve fund as authorized or from the exhibit fund surplus as recommended, the estimated cash balance of the technical department on December 31st would be $1,505.52. Of this amount $1,052,83 would be credited to the special sand research fund and $452.69 to the general technical fund.

The committee also recommended the customary transfer of the sum of $1,000.00 from the funds of the department of exhibits to the funds of the technical department, and the payment of provisional additional compensation of $1,000.00 from the exhibit account to C. E. Hoyt as Manager of Exhibits.

The committee reported that during the year two $500.00 U. S. 4¼% bonds had been purchased with money derived from interest on the reserve fund, making the total par value of government bonds in the reserve fund of the department of exhibits $23,000.00, with a balance of $18.58 in the interest fund.

On motion duly seconded the report of the finance committee was accepted and the recommendations for transfers and appropriations approved and authorized.

Report of Executive Committee

Secretary Hoyt reporting for the executive committee stated that no meetings of the committee had been held since the last annual board meeting, all matters requiring attention having been handled by correspondence.

On motion the report was accepted as read and ordered filed.

Report of Board of Awards

Mr. Clamer, chairman of the board of awards, gave a report summarizing award activities for the year, including conferring the Joseph S. Seaman Medal on Dr. Richard Moldenke and the Wm. H. McFadden Medal on Dr. Robert John Anderson, presentation having been made at the Syracuse convention.

Mr. Clamer concluded his report with a financial statement which showed cash on hand December 1st as $971.92.

On motion the report was accepted as read.

Amendments to By-Laws

The secretary reported that the proposed amendments to the by-laws, approved at the meeting of the board of directors on October 4th, were in accordance with the provisions of the by-laws, submitted to the members for mail ballot. The balloting closed at noon, December 1st. The result was as follows: affirmative votes—548, negative votes—none.

It was moved that the report be accepted and the amendments made effective as of January 1, 1926. Motion carried.

International Test Bar

Jesse L. Jones, chairman of the committee on specifications for Gray Iron Castings, reported that he had been authorized at a members' session and by his committee to present the following resolutions:

RESOLVED, That this meeting refer to the board of directors of the American Foundrymen's Association the recommending by the American Foundrymen's Association of a bar to be known as the International Test Bar, measuring 1.2 inches in diameter, 18 inches between supports, and cast in accordance with A. F. A. standard practice, physical characteristics of the bar to determine properties of the molten iron in the ladle.

BE IT FURTHER RESOLVED, That nothing in this motion is to militate against the use by the British of three bars of varying diameter, or by the French of the Fremont-Portevin Test for judging the quality of gray iron castings.

On motion duly seconded the resolution was unanimously adopted.

Sand Research Committee

Assistant Secretary Kennedy reported on the activities during the year of the Joint Committee on Molding Sand Research. Secretary Hoyt reported that at a meeting of the Executive Committee of the J. C. M. S. R. held in Syracuse, October 6, 1925, it was voted to authorize subcommittee expenditures as follows:

Sub-committee on Tests	$1,500.00
Sub-committee on Conservation and Reclamation	500.00
Sub-committee on Grading	200.00
Total appropriation for sub-committee work	2,200.00

According to the Treasurer's report the expenditures of this committee from January 1 to December 1 totalled $1,442.23. Cash on hand in the special sand research fund on December 1st, $1,110.60.

On motion the report for the committee was accepted and the question of financing 1926 activities referred to the incoming Board.

Cost Committee Report

Director Hageboeck, Chairman A. F. A. Cost Committee, submitted a report covering activities for 1925 and recommended that a similar policy of educational propaganda be adopted for 1926. He asked that the Board authorize, in addition to correspondence with the members, the following activities at the Detroit Convention:

1. Guessing Contest.
2. Estimating Contest.
3. Provision in the program for a cost session.

The report concluded by asking that the Board authorize, if needed, the sum of $500.00 for cost work.

On motion the report of the committee was accepted and the matter of program for 1926 referred to the incoming Board.

Report of Technical Committees

Assistant Secretary Kennedy submitted a report on the activities of the various technical committees and outlined briefly some activities of these committees that would be undertaken in 1926.

On motion the report was accepted as read.

Approval of Acts of Committees of the Board

On motion of Mr. Hageboeck, seconded by Mr. Howell, the Board voted to approve the acts of the officers, the Executive Committee and all other committees during the past year.

Election of L. W. Olson to Honorary Membership

Secretary Hoyt said it was his pleasure to report that at the annual business meeting of the Association in Syracuse A. B. Root, Jr., moved that the Association confer upon retiring President L. W. Olson, at the expiration of his term of office, the title of Honorary Member of the American Foundrymen's Association. This motion, seconded by C. B. Connelley, was submitted by the Secretary and unanimously adopted by a rising vote of the members.

Report of Election of Officers and Directors

The Secretary reported that at the annual business meeting of the Association, October 7, 1925, it was announced that the Nominating Com-

mittee met in Syracuse June 13, 1925, and nominated the following officers and directors:

For President to serve for one year, A. B. Root, Jr.

For Vice-President to serve for one year, S. Wells Utley.

For Directors to serve for three years: Fred Erb, C. E. Hoyt, Jesse L. Jones, L. W. Olson, H. S. Simpson.

That on July 3, 1925, the report of the committee was submitted to the members in accordance with Section 2, Article 9, of the by-laws, that this report quoted Section 3 of the by-laws providing for nominations by petition, and that as there were no further nominations a mail ballot was not required.

On receiving the report it was moved that the Secretary be instructed to cast the unanimous ballot of the members present for those persons whose names appeared upon the ticket presented by the Nominating Committee, Officers and Directors to assume office at the annual meeting of the Board of Directors in accordance with provision of the by-laws. The motion was seconded and unanimously adopted by a rising vote.

Resolutions of Appreciation

Vice-President Root addressing the Chair, said: "With the adjournment of this meeting the terms of office of two of our Directors, who have served the Association exceptionally well, will expire and I move that the Board formally express to Mr. Verne E. Minich, who has served continuously as a Director since 1916, and to Mr. C. B. Connelley, who is just completing a three-year term, our very great appreciation of their many years of active service, and of their interest in all matters having to do with the advancement of the American Foundrymen's Association."

Mr. Clamer seconded the motion, which was adopted by a rising vote.

Adjournment

President Olson: "Gentlemen: This concludes the business of the old Board of Directors. I have no particular recommendations to make to the new Board except to call attention to the advisability of continuing the plan, which we started a year ago, of recording our policies and trying to make them explicit and clear-cut, so as to establish in the minds of all of us, as time goes on and as new members come into the Board, what these basic policies are, and to be rather conservative, perhaps, in changing them to any considerable extent or in any material way.

"I would recommend also that the new Board and the Executive Committee consider the matter of finances rather carefully, not with the idea of adding particularly to our reserve fund, because I think we have a cushion there that is practically as much as we will need, and that we can

take such profit as may accrue to us from our exposition activities and apply it to research. There again I think it far better to carry on this research intensively along a few lines, rather than to spread it out too thin, and in that way get the results that we are looking for.

"If there is no further business, we will stand adjourned and reconvene the new Board at the call of President Root."

Respectfully submitted,

L. W. Olson, *President.*
C. E. Hoyt, *Executive Secretary.*

Minutes First Meeting 1925-26 Board of Directors American Foundrymen's Association at Detroit, Mich., December 8, 1925

President A. B. Root, Jr., presiding.

Upon adjourning the final meeting of the 1924-25 Board, retiring President L. W. Olson handed the gavel to President-elect A. B. Root, Jr., who in calling the meeting to order said, "I do not intend to make any set speech in accepting the presidency of the American Foundrymen's Association. The honor of election to that office is self apparent.

"The retiring officers have concluded the thirtieth year of the American Foundrymen's Association. Those thirty years have been covered by marks of glory all along the path, and if we can continue on the same road that has been travelled, with the same proportionate marks of glory, we have no fear for the future of this Association.

"We have before us this next year probably as much territory to cover and as much activity as the Association has ever undertaken. It will involve additional burdens on us all, and I feel very sure that we will all respond to those additional burdens just as we have in the past.

"The Secretary may now call the roll and we will proceed immediately with the organization of the new Board."

Roll Call

The following responded to roll call: President A. B. Root, Jr., Vice-President S. W. Utley, Directors L. L. Anthes, G. H. Clamer, Fred Erb, A. E. Hageboeck, Alfred E. Howell, Jesse L. Jones, Wm. J. Nugent, C. E. Hoyt, L. W. Olson, and Assistant Secretary R. E. Kennedy.

Nominating Committee

It was moved by Mr. Howell, seconded by Mr. Nugent, that the Chair appoint a Nominating Committee to nominate officers to be elected by the Board in accordance with provisions of the By-Laws. Motion prevailed.

The Chair appointed Mr. Howell as Chairman, Mr. Erb and Mr. Jones, and the committee retired to confer.

President Root: While the Nominating Committee is preparing their report, I will ask Mr. Olson to present a matter which he has in mind for recommending to the new Board.

Mr. Olson: Inasmuch as our 1926 Annual Convention will be in the nature of a National and International Foundrymen's Congress, it occurred to me that it would be nice, as a matter of courtesy, perhaps bringing in other phases of foundry activities, to invite the National Founder's Association to participate in this Congress, if they care to, to the extent of taking some booth space or in some other way setting up headquarters for themselves. To that end I move you, Mr. President, that the Board of Directors of the A. F. A. extend to the N. F. A. an invitation to participate in this manner at our next convention to be held in this city.

The motion was seconded and unanimously carried.

Report of Nominating Committee

Mr. Howell, Chairman: Mr. President and Gentlemen of the Board: Your committee has consulted and begs to make the following recommendations:

1. The Committee recommends that the offices of Executive Secretary, Treasurer and Manager of Exhibits be combined in one, as provided for in the By-Laws, and we nominate Mr. C. E. Hoyt for the office of Executive Secretary, Treasurer and Manager of Exhibits.

2. For Assistant Secretary we nominate Mr. Robert E. Kennedy.

3. For four members of the Executive Committee, to serve with the President, Vice-President and Executive Secretary, we nominate L. W. Olson, C. R. Messinger, T. S. Hammond and W. J. Nugent.

It was moved by Mr. Hageboeck that the report of the Nominating Committee be accepted and that the Board proceed to ballot on the nominees individually.

The motion was duly seconded and carried.

It was moved by Mr. Olson that nomination for the office of Executive Secretary, Treasurer and Manager of Exhibits be closed, and that the Chair cast the unanimous ballot of the Board for C. E. Hoyt.

Motion seconded by G. H. Clamer and carried.

President Root announced that the ballot had been cast as instructed and declared Mr. Hoyt elected as Executive Secretary, Treasurer and Manager of Exhibits.

It was moved by Mr. Hoyt that the report of the Nominating Committee be amended and that Mr. Kennedy be nominated as Technical Secretary, instead of Assistant Secretary.

This motion was seconded by Mr. Olson and unanimously carried.

Mr. Olson moved that the nominations be closed and that the Chair cast the unanimous ballot of the Board for Robert E. Kennedy for the office of Technical Secretary.

Motion seconded by Mr. Nugent and unanimously carried.

President Root announced that the ballot had been cast as instructed and declared Mr. Kennedy unanimously elected as Technical Secretary.

Mr. Clamer moved that the nominations for four members of the Executive Committee be closed and that the Chair cast the unanimous ballot of the Board for the persons nominated.

Motion seconded by Mr. Hageboeck and unanimously carried.

President Root announced that the ballot had been cast as instructed and declared L. W. Olson, C. R. Messinger, T. S. Hammond and W. J. Nugent duly elected as members of the Executive Committee.

Mr. Hoyt moved that the Executive Committee be empowered to act for this Board in the interim between Board meetings on all matters requiring action.

Motion seconded by Mr. Olson and unanimously carried.

Salaries

President Root requested Mr. Olson to take the Chair while he read a report of the Finance Committee prepared for the consideration of the new Board re salaries and transfers. Following reading and consideration of the report, the following action was taken:

On motion duly seconded the salary of C. E. Hoyt as Executive Secretary for the year 1926 was fixed at $5,000.00, payable monthly, $2,500.00 to be paid by the technical department and $2,500.00 by the exhibit department.

On motion duly seconded the salary of R. E. Kennedy as Technical Secretary for the year 1926 was fixed at $4,000.00, payable monthly from the funds of the technical department.

On motion duly seconded the salary of C. E. Hoyt as Manager of Exhibits for the year 1926 was fixed at $6,000.00, payable monthly from the funds of the exhibit department.

On motion duly seconded the salary of Miss Jennie Reininga, as assistant to the Secretary-Manager, was fixed at $225.00 per month, $150.00 to be paid from the funds of the exhibit department and $75.00 from the funds of the technical department.

On motion duly seconded the President and Secretary were authorized to employ such office assistance as was found necessary to take care of Association activities.

Appropriations for Research

It was moved that the Board approve the recommendation of the Finance Committee authorizing the Executive Committee to withdraw the sum of $1,250.00 from the reserve fund for sand research work if they found it advisable to do so.

Motion seconded and unanimously carried.

It was moved that the Board approve the recommendation of the Finance Committee to withdraw the sum of $1,250.00 from the reserve fund for research in cast iron if they found it advisable to do so.

Motion seconded and unanimously carried.

It was moved that the Board approve the recommendation of the Finance Committee to contribute to the Institute of Metals Division of the A. I. M. E. the sum of $250.00 from the exhibit fund surplus.

Motion seconded and unanimously carried.

At this point the Board took a recess for luncheon, resuming at two o'clock at the Statler Hotel.

President Root resuming the Chair called for resolutions authorizing disbursement of funds.

Disbursement of Funds Resolutions

RESOLVED, That A. B. Root, Jr., as President, and C. E. Hoyt as Secretary-Treasurer, be authorized to sign checks and draw against funds deposited in the name of the Association at the Harris Trust & Savings Bank, Chicago; Chicago Trust Company, Chicago; and the Central National Bank Savings & Trust Company, Cleveland.

BE IT FURTHER RESOLVED, That the President and Secretary-Treasurer are hereby authorized to open an account in the convention city for a special convention fund, they to determine how this account shall be opened, and the signatures required for the withdrawal of such funds.

BE IT FURTHER RESOLVED, That the Board authorize a Secretary-Manager's petty cash fund of $500.00, said fund to be reconciled at the end of each month by a full statement of expenditures.

BE IT FURTHER RESOLVED, That all resolutions required by the aforesaid mentioned banks, authorizing the withdrawal of funds of the Association in accordance with the above resolutions, are hereby approved and adopted.

Mr. Hoyt moved the adoption of the resolutions as read. Motion seconded by Mr. Olson and unanimously carried.

Committee Appointments

President Root submitted to the Board a list of committee appointments for the year 1926.

It was moved that the appointments as read be approved and that the Secretary be instructed to notify the chairmen and respective members of the committee, of their appointment and of their approval by the Board.

Motion seconded and unanimously carried.

Election of Nominating Committee for 1926

Presidend Root announced that the next order of business would be consideration of the election of a Nominating Committee, stating that Section 1, Article 9 of the By-Laws provides for the election by the members of the Association of four members of the Nominating Committee, the manner of their election to be prescribed by the Board of Directors.

The method of nominating and election was discussed. It was decided that the Board should select for the ticket eight members, who would be representative both territorially and of the various casting branches of the industry. The members of the Board then selected the following:

J. T. Stoney, Stoney Fdy. Engin. & Equip. Co., Cleveland, Ohio.
Chas. Suess, Westinghouse Electric & Mfg. Co., Philadelphia, Pa
E. S. Van Dalson, Dodge Bros., Detroit, Mich.
W. K. Frank, Damascus Bronze Co., Pittsburgh, Pa.
P. T. Bancroft, John Deere Harvester Works, East Moline, Ill.
R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston, Mass.
John L. Carter, Barlow Foundry, Inc., Newark, N. J.
L. S. Murphy, Marion Malleable Iron Works, Marion, Ind.

Mr. Olson moved that the names selected be printed in the Bulletin as suggestions of the Board and members invited to submit additional names. Motion seconded and carried.

It was understood that if any member was nominated by five or more members, his name would appear on the official ballot.

Cost Committee

President Root called on Mr. Hageboeck, Chairman of the Cost Committee, to again present his report, which had been submitted to the retiring Board and referred to the new Board. After discussion it was moved that the Board approve the following activities of the Cost Committee:

1. Correspondence with members.
2. Guessing contest.
3. Estimating contest.
4. Cost session at the annual convention all at an expense not to exceed $500.00.

Motion duly seconded and carried.

Safety Code Representative

Mr. Hoyt moved that Benj. D. Fuller, who had represented the A. F. A. in drawing up the Joint Foundry Safety Code, be named as our continuing representative in matters of revision of the foundry safety code.

Motion seconded by Mr. Howell and carried.

Advertising in Bulletin

Mr. Olson moved that the Board authorize advertising in the Bulletin and such other arrangements as the Executive Committee may decide upon.

The motion, which was seconded by Mr. Howell, prevailed with the understanding that it was only an authorization for the Executive Committee's consideration.

President Root then called upon each member to express an opinion as to the advisability of carrying advertising in the A. F. A. Bulletin. It was found that the Directors quite unanimously approved of advertising in the Bulletin.

Showing Weight of Castings on Blue Prints

Mr. Utley discussed the advantages of showing the weight of castings on blue prints submitted for price quotations, citing the fact that many associations had endorsed this movement.

Mr. Utley then moved that the Secretary be instructed to write to the Department of Commerce, advising them that the Board of Directors of the A. F. A. favors this movement.

Motion seconded by Mr. Hageboeck and carried.

1926 Convention and Exhibits Committee

Mr. Utley moved that the President be authorized to appoint a Committee on Convention and Exhibits.

The motion was seconded and carried, whereupon President Root announced that he would name the committee later.

Convention Dates

Mr. Olson moved that the dates of the 1926 Convention and International Foundrymen's Congress be from September 27th to October 1st, and that the question of dates of the Exhibit and time of opening and closing be left to the Committee on Convention and Exhibits.

Motion seconded by Mr. Utley and carried.

Mr. Hoyt moved that the Board delegate to the Committee on Convention and Exhibits full authority to make all detail arrangements, decide the price of space, and make rules for governing the 1926 Exhibit.

Motion seconded and carried.

Place of Technical Sessions

The Directors present were unanimous in approving the holding of all technical sessions at the State Fair Grounds, where the exhibits would be held.

Registration and Admission

The Board unanimously approved two classes of registration; namely, members and guests, doing away with the custom of registering individuals connected with member firms as affiliated members.

The Board unanimously recommended that admission to all buildings used on the State Fair Grounds be by badges, which would be supplied gratis to all members and overseas guests when registering, and that there should be a registration fee of $1.00 for all other guests.

Charter Members

Mr. Howell moved that the Secretary be authorized to secure special badges for all charter members of the Association who would be in attendance at the Detroit Convention.

Motion seconded and carried.

International Convention

It was moved by Mr. Olson, seconded by Mr. Erb, that the International meeting be officially designated as the second International Foundrymen's Congress. Motion prevailed.

The Secretary read a report on the International Congress prepared by H. Cole Estep, Chairman of the International Relations Committee. In this report was an estimated budget of expenses which the committee asked be authorized.

On motion duly seconded the question of financing the entertainment of overseas delegates was referred to the Executive Committee with power to act.

It was moved by Mr. Howell, seconded by Mr. Olson, that the Board authorize official invitations being extended to all national, district, and local foundry associations, and to other allied organizations in the United States and Canada, to attend the Detroit Convention. Motion prevailed.

The Secretary reported correspondence re an exhibit on German apprenticeship work at the Detroit Convention. On motion the matter was referred to the Executive Committee with the suggestion that the question be brought to the attention of the A. F. A. Committee on Apprenticeship.

Membership Committee

It was moved by Mr. Howell, seconded by Mr. Erb, that Mr. Utley as Vice-President be made Chairman of the Membership Committee. Motion prevailed.

It was moved by Mr. Howell that the Board instruct the Secretary to write a letter to each district and state chairman, expressing appreciation and thanks for their efforts in behalf of extending the membership during the past year, and ask each to continue as a member of the committee during 1926. Motion seconded and carried.

Invitations for 1927 Convention

It was moved that the President be authorized to appoint a committee to investigate places for the 1927 convention, and that said committee should report to the Executive Committee, who will have power to determine where the 1927 meeting will be held, if in their judgment it is found wise to make such a decision before another Board meeting.

Motion seconded and carried, whereupon the President announced that he would appoint a committee later.

Exhibit Freight Rates

The Secretary brought up the question of securing free return of exhibit equipment.

It was moved that the President appoint a committee with power to negotiate in the name of the Board with the railroads, and if found advisable, with the Interstate Commerce Commission. Motion seconded and carried.

Adjournment

There being no further business, on motion the meeting adjourned.

Respectfully submitted,

A. B. Root, Jr., President,
C. E. Hoyt, Executive Secretary.

Report of Manager of Exhibits for the Year Ending December 31, 1925

Covering 19th Annual Exhibit, Syracuse, N. Y., October 5 to 9, 1925

The following is submitted as a report for the ninth annual exhibit held under the auspices of the American Foundrymen's Association and the nineteenth held in conjunction with the annual conventions of the Association.

This exhibit, which was held on the New York State Fair Grounds, Syracuse, New York, opened at 9:00 A. M. Monday, October 5, and continued through until 3:00 P. M. Friday, October 9. The exhibit was not open on any evening.

The total number of exhibitors was 187, 25 less than the total exhibiting at Milwaukee the previous year. The total space used was 57,370 square feet, an average of 306 square feet per exhibitor. The total space used at Milwaukee was 55,164 square feet, an average of 260 square feet per exhibitor. The average space used at the last six exhibits is 57,229 square feet. The Syracuse Exhibit was third in amount of total space used and sixth in total number of exhibitors. Every space shown on the floor diagram was used with the exception of four in an out-of-the-way location.

The average price of space was 74.3 cents per square foot. The average price of space at Milwaukee in 1924 was 77.4 cents and at Cleveland in 1923 it was 77.8 cents per square foot. Space rental totalled $43,165.00 and was second only to Columbus, where the total revenue from space was $49,755.00.

The total number of freight cars unloaded at sidings on the Fair Grounds was 74. Of this number five contained furniture and two booth material. The total weight of shipments unloaded on the New York Central siding was 1,234,960 pounds, and on the Delaware and Lackawanna 221,957 pounds, a grand total of

1,456,917 pounds, or a little more than 728 tons handled in and out.

All power for operating exhibits had to be brought to the buildings and the buildings wired. The total transformer capacity was 600 K. V. A. The total connected load was greater than at any previous exhibit, except Columbus in 1920.

In the report for the Manager of Exhibits covering the Milwaukee Convention, the statement was made that after two years experience with exhibits opening on Saturday, the management was convinced that the plan had so many advantages over a Monday opening that it should be continued. For a number of reasons, however, it did not seem advisable to consider a Saturday opening at Syracuse. In this report we again emphasize the advantages of a Saturday opening. It is absolutely impossible to have the exhibit ready on Monday morning when the convention opens unless the installation work is completed on Saturday, or we are willing to pay the penalty of double time labor on Saturday afternoon and Sunday and put up with inconveniences resulting from doing work of this kind when express offices, freight yards, shops, etc., are closed. At Syracuse on Saturday afternoon and Sunday there were more than 1,100 hours overtime for electricians, pipe fitters and carpenters on the Association payroll. In addition to this there were the overtime hours for mechanics engaged by exhibitors.

The expense of putting on the Syracuse Exhibit was greater per square foot than for any previous exhibit handled by the Association and greatly in excess of putting on exhibits in the Milwaukee and Cleveland Auditoriums. These auditoriums required very little decoration. Transformer capacity up to the maximum of our requirements was available, as were mechanics and organizations experienced in setting up exhibits. The Syracuse buildings required the maximum of decorating, wiring and fitting up. Organizations and men for doing this work had to be brought out from Syracuse and from other cities. Booth work and decorations cost $3,003.14 more than the previous years, and power $3,240.19 more, these two alone totalling $6,243.33.

We did not pay rent but were required to clean and repair buildings and grounds. This was done at a cost of $537.45. When this was completed, we were given a letter by the Secretary of the State Fair releasing us from any further responsibility in the matter of the $5,000.00 surety bond which we had given.

Respectfully submitted,

C. E. HOYT, *Manager of Exhibits.*

Annual Report of Secretary-Treasurer

To the President and Members of the American Foundrymen's Association, Inc., Gentlemen:

Technical activities of the Association are covered in detail elsewhere in this volume and have been reported throughout the year in the Quarterly Bulletin. Minutes of board meetings are given in full in the report for the Board of Directors. This report will, as has been customary, point to some of the outstanding general activities of the past year, record membership data and give account of financial operations.

Technical Activities

We believe that all who have observed have noted with satisfaction the increased value of our technical activities. Our committees are gradually becoming stronger each year. Better programs are the result. Credit for all this is due R. E. Kennedy. This was recognized by the Board of Directors when at the annual meeting in December they unanimously advanced Mr. Kennedy from Assistant Secretary to full Technical Secretary; a recognition richly deserved.

Amendment to By-Laws

The object of the Association is the assembling and dissemination of information that will improve methods of production in foundries and improve quality of the product. It has long been felt that all this could be accomplished in a larger way if we could interest a greater number of men directly responsible for production and product. It was this thought that prompted certain amendments to the By-Laws that reduced cost of membership to a minimum and it is hoped that during 1926 many of these men who have much to give and who can profit by the giving, will become affiliated with the A. F. A.

International Meeting

It will be the privilege of the American Foundrymen's Association to be hosts for the Second International Foundrymen's Congress. The first Congress, which was held in Paris in 1923, paved the way for international acquaintanceship among foundrymen of all countries and provided an opportunity for interchange of experiences and practice. All this will result in world-wide advancement of the arts and sciences pertaining to the production of castings.

Membership Committee

During the past year under the direction of Vice-President A. B. Root, Jr., as General Chairman, there was organized a country-wide membership committee. Sixty-seven State and District Chairmen were appointed. The organization was not completed until July and the year was half gone. As a direct result of the interest and co-operation of this committee we had a larger increase in membership than for any year since 1920. This committee will be kept intact during 1926 and under the direction of Vice-President S. W. Utley, who succeeds Mr. Root as General Chairman, it is confidently expected that the number of new members elected will be more than double the number elected in 1925.

Membership

Our book membership on December 31, 1924, was 1,622, total number of new members elected during that year was 177 and the net gain for the year was 62. During the year 1925, 240 new members were elected. Our best months were August, September and October, there being a total of 39 elected each month. Seventy-five resignations were received during the year. As usual, the majority of these were from firms going out of business or from individuals no longer connected with the foundry industry. Number of delinquents dropped, 30; removed by death, 3; making a total of 108. The net gain for the year was 132, or 8.13%, as against a gain of 4% the previous year. The total mem-

bership on December 31, 1925, was 1,754. Of this number 21 are delinquent for 1925 dues.

Finances

Association funds are kept in two separate accounts, one for the Technical Department and one for the Exhibit Department. The auditor's statement, which is a part of this report, shows receipts and disbursements for each department. The total receipts for the Technical Department as shown in the statement are $27,273.65. It will be noted that in this is included the transfer from the Exhibit Department of $3,500.00; $2,500.00 of this amount was authorized at the annual board meeting in November, 1924, as an appropriation to the support of sand research.

The total expenses for the year were $26,663.63; $942.11 less than the previous year. The average cost per member was $15.20; a decrease in expense per member of 93 cents over the previous year.

These reductions in expenses are gratifying in view of the fact that the bound volume of Transactions printed during the last year was 50% larger than ever before and was printed in two parts. Due to the fact that Part II consisted largely of tables, tabulations, and reports showing results of geological surveys in molding sand, the increased cost of the transactions was approximately 60%.

Research Funds

The Cleveland Research Fund which was started by a contribution from the Cleveland Foundrymen's Committee following the 1916 convention, and a further contribution following the 1923 convention, with interest and including $100.00 offered by the Penton Publishing Co., for the foundry memory contest at the Syracuse Convention, now totals $1,310.90.

In the Rogers Brown Research Fund we have $535.97, and in the general Sand Research Fund, $999.19. Research is also credited with $2,500.00 authorized by the Board of Directors at the annual board meeting on December 8, for special research during the year 1926.

Cash on hand in the Awards Fund Interest account is $983.23. This represents the unused interest in the four major awards funds of $5,000.00 each, and one fund of $1,000.00.

We acknowledge with sincere appreciation the co-operation of all authors of papers and reports whose contributions have made for a successful year.

For the support of President Louis W. Olson, Vice President A. B. Root, Jr., the Board of Directors, Technical Secretary R. E. Kennedy, Assistant to Secretary-Treasurer Jennie Reininga, and of all the staff, we express hearty appreciation and thanks.

Respectfully submitted,

C. E. HOYT, *Secretary-Treasurer.*

Auditor's Report

Chicago, January 16, 1926.

Mr. A. B. Root, Jr., President,
American Foundrymen's Assn.,
Chicago, Ill.

Dear Sir:

In accordance with instructions received from you by telegram, we have audited the books of the American Foundrymen's Association for the year ended December 31, 1925. Our audit cover the examination of the books of the Department of Exhibits and of the Technical Department for the year. We now submit our report thereon, together with the following statements:

DEPARTMENT OF EXHIBITS

Statement of Cash Receipts and Disbursements for the year ended December 31, 1925	Exhibit A
Balance Sheet as at December 31, 1925	Exhibit B

TECHNICAL DEPARTMENT

Statement of Cash Receipts and Disbursements for the year ended December 31, 1925	Exhibit C
Balance Sheet as at December 31, 1925	Exhibit D
Special Fund Accounts as at December 31, 1925	Exhibit E
Trust Fund Securities	Schedule I

DEPARTMENT OF EXHIBITS

Cash Receipts and Disbursements—A classified statement of the cash receipts and disbursements of this department for the year ended December 31, 1925, is presented on Exhibit A. The total cash receipts amounted to $50,080.29, while the disbursements were $51,140.43. The balance of cash in bank and on hand at the close of the year was $1,908.26 as evidenced by certificates which we obtained from the banks.

Balance Sheet—The balance sheet, Exhibit B, shows the assets and liabilities carried on the books of this department after closing out the operating accounts for the year.

The accounts receivable consist of balances due from exhibitors for power furnished, $368.36, and an amount due from the Technical Department of $300.54, representing a portion of convention expenses for which the Department of Exhibits is to be reimbursed.

Notes receivable consist of notes given by Henry E. Pridmore Company, which are considered doubtful of collection. We verified the furniture and fixtures account and computed depreciation for the year at the established rate of 10 per annum.

The securities representing investment of the Reserve Fund were verified by a certificate furnished by the Harris Trust & Savings Bank, Chicago, where they are held for safe keeping. The securities which are carried on the books and stated on the balance sheet at cost have a present

market value considerably in excess of cost. The securities consist of the following:

Description	Rate of Interest	Cost	Par Value
United States Liberty Loan Bonds:			
2nd Converted	4¼%	$16,504.67	$18,000.00
Fourth	4¼%	5,111.09	5,000.00
		$21,615.76	$23,000.00

TECHNICAL DEPARTMENT

Cash Receipts and Disbursements—The cash transactions of the Technical Department for the year ended December 31, 1925, are summarized on the Statement of Cash Receipts and Disbursements, Exhibit C. The total receipts amounted to $27,273.65 and the disbursements to $26,663.63. The cash balance at December 31, 1925, was $3,428.35.

Balance Sheet—The Balance Sheet, Exhibit D, has been drawn up to show the status of the General Fund and Special Funds as at December 31, 1925. The cash in banks was verified by certificates furnished by the banks and a reconciliation thereof with your cash records.

The securities representing investments of the Award Funds as listed on Schedule I were verified by a certificate received from the Harris Trust and Savings Bank. These funds are held in trust under trust agreements which provide that only the income from the investments is available for award purposes.

Special Fund Accounts—The transactions for the year affecting the various Special Funds (including the Award Fund Income) and the resulting balances at December 31, 1925, are summarized on Exhibit E.

With reference to the General Research Fund, which was appropriated in December, 1924, and is shown on the books as due from the Department of Exhibits, we note that the Treasurer's report of December 8th stated that it had not been deemed best during the year to take the $2,500.00 appropriation from the Reserve Fund and apply it to Research, as recommended by the Finance Committee in December, 1924.

We are pleased to report that we found the books and records of the Secretary's office in good order and wish to acknowledge the facilities afforded and assistance given our representatives by the Secretary and the employees of his office for the purpose of this audit.

Respectfully submitted,

(Signed) JOHN K. LAIRD & COMPANY,
Certified Public Accountants.

EXHIBIT A

Department of Exhibits

Statement of Cash Receipts and Disbursements for the year ended December 31, 1925

Cash Balance, December 31, 1924:		
Standard Trust and Savings Bank		$ 2,474.40
Petty Cash		494.00
		$ 2,968.40
Receipts:		
Rental Space	$42,697.50	
Permits	4,675.00	
Registration Receipts	513.12	
Accounts Receivable	1,404.55	
Exhibitor's Registration	579.00	
Interest on Bank Deposits	139.11	
Notes Receivable	72.01	50,080.29
		$53,048.69
Disbursements:		
Manager's Salary		7,600.00
Additional Compensation, Manager		1,000.00
Advertising		4,707.31
Auditing		235.00
Booth Work		6,771.36
Badges		348.01
Building Rental		1,919.25
Cleaning and Repairing		604.65
Committee Traveling		2,608.95
Convention Expense—Exhibits	770.07	
Convention Expense—Technical	300.54	1,070.61
Exchange		23.73
Furniture and Fixtures—Typewriter		135.00
General Expense		108.77
Installation—Labor and Material		849.70
Installation—Superintendent and Assistant		1,323.00
Insurance		223.50
Janitor Service		448.95
Manager and Assistants—Traveling		1,705.03
Office Expense		283.01
Postage		576.12
Power		5,515.83
Printing and Stationery		1,899.96
Registration		969.40
Office Rent		880.00
Stenographic and Clerical		4,865.40
Taxes		10.54
Telephone and Telegraph		350.50
Watchman and Doorman		206.85
Transfer to Technical Department		3,500.00
Donation to A. I. M. E.		250.00
Hans Lochen & Co. for Installation, Milwaukee		150.00
		$51,140.43
Cash Balance, December 31, 1925 (Exhibit B)—		
Chicago Trust Company	$1,408.26	
Petty Cash	500.00	1,908.26
		$53,048.69

EXHIBIT B

Department of Exhibits

Balance Sheet as at December 31, 1925

Assets

Cash in Bank		$ 1,908.26
Accounts Receivable:		
Exhibitors' Accounts	$ 368.36	
Technical Department	300.54	668.90
Notes Receivable		432.06
Furniture and Fixtures	729.24	
Less: Reserve for Depreciation	274.05	455.19
Total General Fund Assets		$ 3,464.41
Reserve Fund:		
U. S. Liberty Loan Bonds (par value $23,000.00)	$21,615.76	
Cash	18.58	
Prepaid Interest	1.89	
Total Reserve Fund Assets		21,636.23
		$25,100.64

Liabilities

General Fund Surplus		$ 3,464.41
Reserve Fund:		
Due Technical Department	$ 2,500.00	
Surplus	19,136.23	21,636.23
		$25,100.64

EXHIBIT C

TECHNICAL DEPARTMENT

Statement of Cash Receipts and Disbursements for the year ended December 31, 1925

Bank Balance as at December 31, 1924, Harris Trust and Savings Bank		**$ 2,818.43**
Receipts:		
Membership dues and Entrance fees—		
For 1925	$21,474.73	
For 1926	505.50	
Convention Registration Fees	1,291.88	
Refund to Sand Research	169.75	
Transfers from Exhibits Department	3,500.00	
Accounts Receivable	199.44	
Bank Interest	132.35	
Total Receipts		$27,273.65
		$30,092.08
Disbursements:		
Committee Expenses	$ 920.30	
Convention Expenses	1,142.24	
Discount and Exchange	72.07	
Dues in other associations	30.00	
General Expenses	71.75	
Membership Campaign	284.22	
Office Expense	135.34	
Postage	1,412.04	
Printing and Stationery	1,472.85	
Publications	10,950.91	
Rent	440.00	
Salaries, Secretary and Assistant	6,000.00	
Stenographers and Clerical Salaries	1,685.98	
Telephone and Telegraph	33.94	
Traveling Expenses	288.60	
Sand Research Expenses	1,723.39	
Total Disbursements		26,663.63
Cash Balance, December 31, 1925		**$ 3,428.45**

EXHIBIT D

TECHNICAL DEPARTMENT

Balance Sheet as at December 31, 1925

ASSETS

General Fund:		
Cash in Banks		$ 3,428.45
Accounts Receivable—		
For 1925 Dues	$ 352.00	
Department of Exhibits	2,500.00	2,852.00
Furniture and Fixtures	$ 628.95	
Less: Reserve for Depreciation	377.40	251.55
Inventories		1,137.98
		$ 7,669.98
Special Funds:		
Cash in Bank		2,829.10
Total Assets—General and Special Funds		$10,499.08
***Trust Funds:**		
Securities		21,000.00
		$31,499.08

LIABILITIES

General Fund:		
Accounts Payable—Department of Exhibits		$ 300.54
Prepaid Dues for 1926		505.50
Surplus		3,364.75
		$ 4,170.79
Sand Research Fund	$ 999.19	
General Research Fund	2,500.00	3,499.19
		$ 7,669.98
Special Funds:		
Cleveland Research Fund	$ 1,310.90	
Rogers Brown Fund	535.97	
Award Fund Unexpected Income	982.23	2,829.10
		$10,499.08
Trust Funds:		
McFadden Award Fund	5,000.00	
Seaman Award Fund	5,000.00	
Whiting Award Fund	5,000.00	
Penton Award Fund	5,000.00	
Obermayer Award Fund	1,000.00	21,000.00
		$31,499.08

*These funds are held under trust agreements which provide that the income only is available for distribution.

EXHIBIT E

Technical Department

Special Fund Accounts as at December 31, 1925

	Award Fund Income	Cleveland Research Fund	Rogers Brown Fund	Sand Research Fund	General Research Fund
Balance December 31, 1924...	$1,462.73	$1,310.90	$535.97	$2,722.58	$2,500.00
Receipts:					
Interest on Bonds.....	980.00	.....	.....	.....	.....
Interest on Bank Deposits....	19.85	47.00	15.72	.....	.....
Penton Publishing Co. Donation	.....	100.00	.....	.....	.....
Reimbursement on Equipment..	.....	.....	.....	169.75	.....
	$1,462.73	$1,310.90	$535.97	$2,722.58	$2,500.00
Expenditures:					
Committee Expense in connection with Sand Research work	.....	.....	.....	1,723.39	.....
Prizes and Awards.....	480.50	.....	.....	.....	.....
Balance, December 31, 1925.....$	982.23	$1,310.90	$535.97	$ 999.19	$2,500.00

Louis H. Olson

Annual Address

By The President, Louis W. Olson

This year completes the thirtieth in the life of this association and this meeting is the twenty-ninth meeting. Many of the original founders have discontinued active participation and some have crossed the great divide. A new generation of workers has been in training and new corps of leaders are in command. When this association was founded your President was still in his teens and had no tangible conception of a foundry nor any knowledge of its problems. Most enterprises having a modest beginning go through a period of difficulties and hardships and it is only because of the ability and courage of a few who took the lead that success finally came as a reward for their efforts. The American Foundrymen's Association owes its success to the unselfish effort of its founders and early leaders and also, and again to the vision, courage and loyalty of a small group later on when it became necessary to incorporate. It must be very evident to us now that these men had a wonderful vision and ability when they organized and initiated a force as vital, beneficial and far reaching as this association now is in the life of the foundry industry.

Greater Recognition of A. F. A. Activities

Like most successful and stable enterprises our growth has been slow but steady both in number of members and in amount of service rendered. In many cases a point is reached after which this growth and development seems to proceed more rapidly, perhaps because of an accumulative growth of good will, confidence, and obviously effective service. It seems, then, that we are now on the threshold of a new period in our development: that of a more rapid growth in membership, a more highly organized service as an association and a much freer interchange of experiences as individuals. Our membership growth is actually becoming more rapid, your assistant secretary, Mr. Kennedy, is directing the technical activities of your association in a very able way and the results of his efforts are becoming manifest. A

larger number of our members are from time to time entering into participation in our activities. We are today accorded the recognition we deserve by other societies and associations. We are being invited to participate in investigations, standardization and research. The direct result of all this is a wider scope in our activities and a participation through committees and conferences by a larger number of our members in a large variety of activities. This naturally brings about a freer acquaintanceship and a more widespread understanding of the individual attainments which in return reflect credit on our association.

Plans for International Foundrymen's Congress

I wish to call attention at this time to the plans being made for an International Foundrymen's Congress and Exhibition to be held in Detroit in 1926. Complete arrangements will be forthcoming in due time. This, however, to me is a definite indication of the growth and progress of our association and the recognition we are being accorded. True, it is too soon to count the attendance and measure the interest but we are already seeing evidence abundantly of this interest and can even at this early date say the attendance from overseas countries and particularly from Europe, will be limited only by the financial restrictions that prevail, and as you all know these are more of a factor abroad than they are here. But this event promises to be a distinct marker in our record of progress and a recognition of our attainments in the field of foundry activity. More than this it should be productive of a more widespread understanding and more intimate relations. The ability of your association to entertain and to undertake to a successful conclusion a project of this magnitude is only another indication of our growth and progress.

Obligations of Members

There are primarily two obligations that every member owes to his association. The first is to contribute from his experience, knowledge and ability to the work of the association, and the second is to use his influence on friends, acquaintances and others to procure new members. Under the first obligation one might assume it to be exemplified only in the writing of papers. This

is not so. While the procuring of papers is a difficult matter at times and one which gives the papers committee anxiety still another and very important function of the association is the work of the various committees. No member, however reluctant he may be to prepare a paper, should hesitate to serve on a committee handling a subject in which he is competent to advise and be helpful. The difficulty comes in ascertaining the accomplishments and attainments of our members so as to make up the personnel of various committees. One suggestion would be to faithfully attend all sessions treating subjects coming within your scope and to give freely of your knowledge and experience by entering into the discussion and bringing out all phases of the subject. If you hesitate to talk in public you may submit your discussion in writing either before or after the meeting. You will find that when you do this it will not only clarify and coordinate your own convictions in a wonderful way, but it will also establish yourself among your fellow members as one having expert knowledge or useful experience along certain lines and you will consequently be exposing yourself to an invitation to more effectively participate in our activities.

Any organization large or small is effective in its results in increasing the sum total of human knowledge not so much through any super-intelligence vested in one or a few directing minds, but more through the accumulative efforts of all these minds working in harmony and with a complete understanding among them as to abilities and achievements, and willingness to give and take. No man is more unfortunate than he who thinks he knows it all, and on the other hand, no man can be more fortunate than he who has a large circle of friends and acquaintances who are willing to give help and advice from their knowledge and experience.

Do not be misled into making either of two common errors. One is to believe that your procedure and knowledge is so highly specialized that no one else could have any interest in it or could glean any useful information from it and the other is to believe that your operation is so commonplace that you have nothing to offer. Frequently, a knowledge of procedure in lines quite different may be the nucleus of an application in a slightly different way to some problem of your own and again many very important

developments have had their origin in what seemed at first to be a very simple and supposedly well understood fact. Many of us are inclined to minimize our attainments because the development has been slow and not startingly obvious but never-the-less definite and actual, and fail to appreciate the change until perchance a retrospection is indulged in.

I consider myself very fortunate in having had the opportunity of close contact with many of the leaders in the foundry industry, and I can, therefore, perhaps appreciate the more fully the benefits and advantages that accrue from a free interchange of ideas and experiences. I know of no better medium through which to accomplish the development of the production phase of this industry than The American Foundrymen's Association. Continued growth and success of our association must mean continued growth and success of the industry that you and I are engaged in, and it matters little whether we are in it through choice or circumstance, my plea to you is, then, to avail yourselves fully of all the facilities it has to offer and help to make it grow and become more useful by your participation, interest and effort.

In conducting the affairs of your association there is a vast amount of detail to be accomplished. This is accentuated in the arrangement, direction and management of the exhibition. Each president realizes fully as his term of office is about to expire, if not before, the correctness of this statement. I cannot refrain from expressing my sincere admiration for the work of your secretary, Mr. Hoyt, and his able staff and for the work of Assistant Secretary Kennedy. This may seem like a formal courtesy, but I am only voicing a sincere conviction resulting from a year's close contact and observation with this work. I have seen so many instances of administrative ability, sound business judgment and straightforward dealing coupled with fine diplomacy that I would be remiss if I did not direct your attention to it.

I wish also to take this opportunity to express my appreciation for the interest and cooperation of Vice President Root, members of the board of directors, and all the past presidents, who have so graciously given of their time to help whenever called upon, and who are so well qualified by their broad business

experience and by their intimate knowledge of the affairs of this association to give advice and counsel. We are indeed fortunate to have so many past presidents who continue to take an active interest. I shall deem it an obligation which I shall aspire to fulfill to continue an active interest and a helpful participation in the affairs of this association after my official contact shall cease and I sincerely trust that such humble effort as I may have made has been productive of at least a slight increment of progress and growth.

Some Fundamental Relationships in Cast Iron, Wrought and Steel Manufacture*

By J. E. Fletcher, Birmingham, England

Whilst dealing with the many and complex problems brought before the research committees of the British Cast Iron Research Association, the author has found the value of a long experience in iron and steel foundry, blast furnace and wrought iron practice.

All ferrous processes have much in common and the student who wishes to understand any one section of iron and steel works metallurgy is increasingly compelled to correlate the fundamentals of every other section.

In particular the relationships existing between the structural properties of cast iron, wrought iron, malleable cast iron and steel are of fundamental importance.

In Britain the monumental work of Henry Marion Howe is thoroughly recognized and in placing that indefatigable worker alongside our own John E. Stead, every English speaking metallurgist and laborer in the field of iron works practice would seek to rival his fellow in paying tribute to the memory of the two men who have done most to further the all-round quest of knowledge and advancement in metallurgical science.

To Deal with Special Subjects

In this paper it is sought to cover only a few of the related areas in the field of ferrous research and to discuss them in such a manner as will suggest avenues to further thought and research of a practical character.

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*This paper is one of a series on foundry problems being annually exchanged with the Institute of British Foundrymen. This is the fourth exchange paper presented by members of the British organization. Mr. J. E. Fletcher is consultant for the British Cast Iron Research Association and has been actively identified with the development of research in the British foundry and wrought iron industries. He acted as director of the British Cast Iron Research Association during the first two years of its existence and is now a member of the Council of that association.

The subjects touched upon may be briefly summarized as:

(1) The influences operating in the production of the common base of all iron and steel works and foundry processes, pig iron. Temperatures and other effects as responsible for differences in the chemical and structural composition of the blast furnace product. The fracture index and its relation to chemical and micro-structural analysis.

(2) The effect of remelting on the primary or pig iron structure and the relationship between the final structure of cast iron, wrought iron and malleable iron and the original pig iron structure.

(3) The function of working slags and their dominant fluid conditions and composition. The neutral and active conditions of the slags in various ferrous processes.

(4) The inter-relationships of micro-structure in cast iron, wrought iron, malleable cast iron and steels. Stable and unstable structures.

(5) The scrap problem and the influence of the increasing use of scrap in modern iron and steel making.

The Blast Furnace Product

At this moment the cast iron, wrought iron, and steel making industries are dependent upon pig iron from the blast furnace as their basis. Direct metal from the blast furnace for castings and through the mixer for open hearth steel is possibly increasing in favor as a means of producing cheap iron castings and structural steel but in the manufacture of such castings and wrought iron as must meet the "safety first" conditions of the modern engineer, remelted pig iron has not yet been superseded.

With the gradual deterioration of reworked scrap the need for good virgin metal in the form of pig iron of dependable chemical and structural analysis is a necessary corrective, for it must be remembered that methods for desulphurizing and otherwise chemically improving the composition of scrap ferrous metals may be at the expense of the physical well being of the structural constituents thereof.

Differences in Pig Irons of Similar Chemical Analysis

Two blast furnaces, differing in design and size, using different classes of ores and fuel, with dissimilar driving rates and blast temperatures, may produce pig iron of like chemical analysis. The results obtained from the remelted pig iron, whether in the form of iron or steel castings, wrought iron bars or malleable castings may be, and often is greatly different. Can it be expected that the pig iron produced in a small slow working furnace smelting lean ores with cold blast supply shall have the same physical structure as another iron run from a large hard driven furnace working on rich ores and using a hot blast supply?

During the war period the shortage of hematite iron compelled blast furnacemen to charge steel and wrought iron scrap with high phosphoric ores and puddling cinder. In many cases the pig iron analysis approximated to that of well known and celebrated cold blast brands of foundry iron but the physical structure of the semi-steel type of iron was vastly different from the cold blast variety.

The above matter is of fundamental importance and the author, whilst realizing that a pig iron of given analysis will, in the hands of a capable iron or steel founder, enable iron or steel of desired chemical analysis to be produced, knows from experience that the physical characteristics of irons produced under different smelting conditions are not alike though the chemical analyses may be very similar. The same physical differences are noticeable in the puddled iron produced from two differently smelted irons of similar chemical analyses. In steel production the products obtained from American washed iron and Swedish charcoal smelted irons of similar chemical composition are unlike in physical properties and parallel differences have been regularly noted in pig irons for malleable casting processes.

Reasons for the Differences

There can now be little doubt that the chief differences lie in the following direction:

(1) Combustibility of fuel and rate of combustion per hour per square foot of furnace area at level of maximum combustion.

(2) Weight of air supply per pound of fuel burnt per hour.

(3) Weight of iron produced per square foot of furnace area at maximum combustion level, per hour.

(4) Volume of ores or other metal producing portions of furnace burden per cubic feet of gases at mean temperature between level of maximum combustion and furnace top exit—in terms of volume per square foot of furnace area at maximum combustion level per hour. This being a measure of the ore volume passing through one square foot of furnace area per hour during the reverse passage of 1000 cubic feet of gas per hour through the same area.

(5) Composition and temperature of the gases between level of maximum combustion and furnace top.

(6) Porosity and gas permeability factors of fuel and ore burden, involving lump size of ore and coke and porosity of the individual ore and coke lumps. Where high limestone or other flux additions are made the effect of flux lump size must be taken into account.

(7) Composition and volume of slag produced, in terms of slag weight and volume per square foot of furnace area at level of maximum combustion, per hour. Mean temperature of working slags and mean thickness of slag on metal in furnace hearth.

(8) Mean temperature of molten metal when tapped.

(9) Mean time period during which metal is accumulating in furnace hearth between tappings, together with mean depth of metal in furnace hearth.

(10) Character of various ores, etc., in mixtures and their distribution as charged. Reducibility and carburizing effect on various ores as affected by porosity or fineness of ores and by velocity of ascending gases and their composition and temperature.

(11) Height of charge column. Stock line to maximum combustion level. Tuyere level to maximum combustion level. Tuyere level to bottom of furnace hearth.

(12) Effect of blast velocity through tuyeres on air distribution. Oxidation in outer ring zones of charge column.

Difference in Blast Furnace Practice

In this paper it is impossible to do more than touch upon some of the points above mentioned but, as the problem is of such vital importance to the foundryman, a few brief notes on the differences in blast furnace practice may be of service. Take for example, two blast furnaces making foundry iron of 2 per cent silicon, 1 per cent phosphorus grade; one more hardly driven than the other, the first making about 6 tons per working hour, the second 3 tons. The blast temperature in the first furnace is taken

Table 1

	No. 1 Furnace	No. 2 Furnace
(a) Iron made per sq. ft. of furnace area at level of maximum combustion (8 ft. above tuyere level in No. 1 and 6 ft. in No. 2 furnace).....	100 lbs. per hour	70 lbs. per hour
(b) Coke burnt per sq. ft. of furnace area at maximum combustion level per hour.....	150 lbs.	100 lbs.
(c) Ore volume passing per hour in terms of cubic ft. per sq. ft. of max. combustion zone area.....	5 cubic ft.	1.3 cubic ft.
(d) Hot gases passing each cubic foot of ore per hour. Taken at level midway between maximum combustion zone and stock line.....	6900 cubic ft. at 950 F.	27200 cubic ft. at 1050 F.
(e) Mean velocity of burden descent from stock line to tuyere level....	3.65 ft. per hour	3 ft. per hour
(f) Metal rises in hearth at rate of....	8.5 inches per hour	5 inches per hour
(g) Mean thickness of slag blanket on top of metal in hearth.....	32 inches	19 inches
(h) Temperature of throat gases.....	380° F.	600° F.
(j) Weight of slag per sq. ft. of furnace area at maximum combustion level per hour.....	150 lbs.	60 lbs.

at 1200 degrees Fahr. and in the second 1000 degrees Fahr. Furnace No. 1 has a hearth 11 feet 6 inches diameter and a height of charge column (from tuyere level to stock line) of 62 feet. Furnace No. 2 has a hearth 10 feet 0 inches diameter and a height of charge column of 60 feet. The iron content of the ores in No. 1 averages 25 per cent when calcined whilst that of No. 2 is 45 per cent. The slag produced per ton of iron in No. 1 is 30 hundred weight, that in No. 2 twenty hundredweight; the coke consumption per ton of iron smelted being 30 hundredweight in No. 1 and 28.5 hundredweight in No. 2. From a closer examination of the furnace working the comparative data of Table 1 have been deduced.

In order to visualize what is happening whilst the ore is descending from the stock line to the hot zone in the furnace

boshes, that is, the level of maximum rate of combustion, it is useful to conceive the iron oxide which is being reduced to metallic iron as in the form of grains of 1 millimeter cube. In Furnace No. 1 the lean ore, 24 per cent iron content, contains roughly one grain of iron oxide (Fe_2O_3) to 2.5 grains of earthy oxides, the millimeter cube of iron oxide being coated by a .25 millimeter thick film of silica, lime, alumina, etc.

When the iron oxide is reduced to metallic iron each, 1 millimeter cube of reduced iron becomes surrounded by a jacket of slag forming matter nearly .5 millimeters thick.

Similarly in Furnace No. 2 each 1 millimeter cube of iron oxide is covered by a thin film of earthy oxides only 0.1 millimeter

Table 2

	No. 1 Furnace	No. 2 Furnace
Thickness of slag forming oxides covering 1 mm cube nucleus of iron oxide	0.25 mm	0.10 mm
Thickness of gas film enveloping the ore grain	0.20 mm	0.15 mm
Thickness of slag forming oxides covering 1 mm cube nucleus of reduced iron	0.42 mm	0.18 mm
Thickness of gas film enveloping the gangue covered iron grain	0.24 mm	0.17 mm

thick. The reduced iron grain is later covered by a film of slag forming oxides 0.18 millimeters thick. It is of course impossible to assume that such homogeneity of structure exists in the ore mass but these means of visualization of the disposition of the iron grains amidst the earthy gangue are helpful to the critical student.

Further, as the measurement of the cubic content of average ore bulk shows that the cubic contents of the voids between the ore lumps is approximately equal to the volume of the solid ore grains the mean thickness of the gas film covering the gangue-covered iron oxide and reduced iron grains is of further interest as shown in Table 2.

In Table 1 it will be noted that about 4 times the volume of hot gases sweep past each cubic foot of ore in Furnace 2 than in Furnace 1. Hence the gas effect must be considerably more po-

tent when in contact with the thin covered iron grain in Furnace 2 than in the case of the thicker covered grain in Furnace 1.

The preheating of the ore and reduced iron during its descent from the stock line to the fusion zone, level of maximum combustion rate, must be greatest in Furnace 2, where the escaping throat-gases are 600 degrees Cent. This means that iron reduction takes place higher in the furnace stack in No. 2 than in No. 1. It also follows that the carburization of the iron grains proceeds more rapidly in Furnace 2 because of the more ample gas supply, the grains coming into contact with richer gas at higher temperatures than in Furnace No. 1. The resulting iron will therefore be higher in total carbon content in No. 2 than in No. 1 for, in addition to the richer and hotter gas supply and accompanying higher preheating effect, the burden takes longer to pass through the furnace in No. 2 than in No. 1. The total carbon content of the iron must obviously correspond with the degree of carburization of the iron grains reduced from the oxides (i. e., the spongy iron) at the time such grains have descended to the temperature level corresponding to the melting point of the carbon-iron alloy produced.

If the ore is rich in iron content and is readily reduced then, if the hot gases produced by burning an excess of carbon per unit area at the level of maximum combustion, per hour, raise the temperature of the preheating zone above that level the fusion level will be raised.

This melting level will be fixed by the proportion of coke to iron in the burden but will vary with the reducibility of the ores or other iron-yielding ingredient in the burden. Thus hematite ore and furnace cinder may contain equal percentages of iron but the first will require less coke per ton of iron yield and the rates of smelting in the same furnace will differ. The hematite ore will be reduced at a higher level than the flue cinder which, as a slag, melts before its iron content is reduced; hence the iron reduced from the cinder is not so highly carburized as that from the hematite. Similarly the iron reduced from a lean ore may descend low into the furnace before it is reduced, carburized and fused, a low carbon iron being the result.

Again, in the same furnace the ratio of coke to ore burden may be greatly different whilst working the same ore. By different rates of driving the iron produced will correspondingly differ in total carbon content, the level of maximum combustion being thereby altered, the rate of carburization affected and the melting zone level raised or lowered.

All these modifications affect the structural composition of the cast iron produced, even though the chemical composition be little different in irons smelted from such different raw materials as flue cinder and lean oolitic ores.

It is to be feared that many foundrymen are ignorant of the difficulties which confront blast furnacemen engaged in the manufacture of foundry pig iron, especially in those countries where the composition of ores is continuously varying.

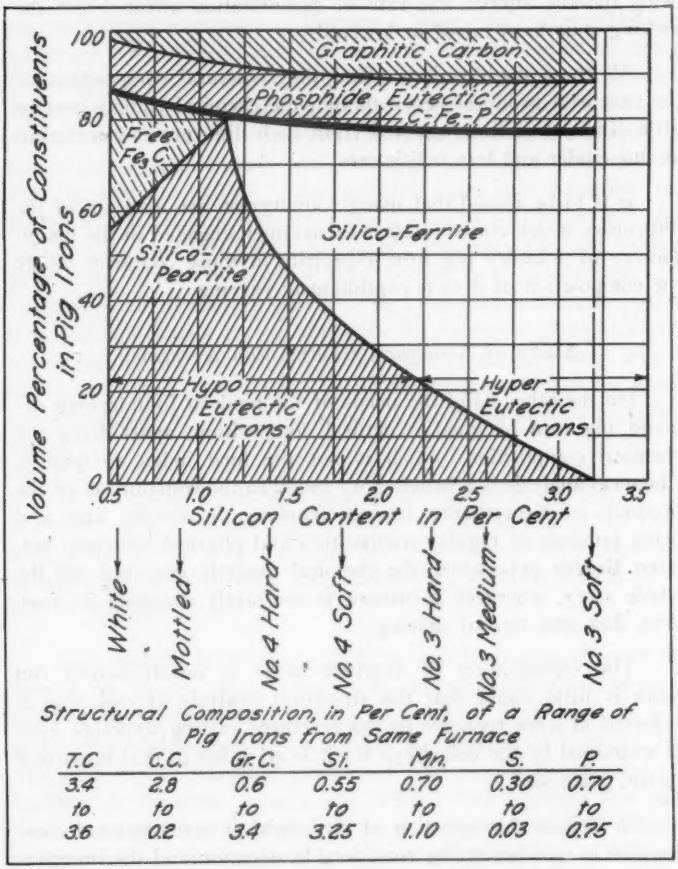
Study of Structural Composition Necessary

On the other hand the needs of the modern foundryman demand pig iron of good structural composition, apart from the chemical composition, which is not the final index to quality. Chemical analysis is a satisfactory index to the constitution of the products of a particular furnace working on definite lines and using burdens of regular composition and physical structure but, from British experience, the chemical analysis does not tell the whole story, wherever a furnace is constantly changing its fuel, ores, flux and rate of driving.

The examination of fracture alone is unsatisfactory but there is little doubt that the structural analysis of cast iron is reflected in some measure by the fractured casting structure even as examined by the naked eye for it is an index to that important factor, grain size.

In Britain this question of structural or constitutional composition is now occupying considerable attention and the interpretation of the chemical analysis of cast iron in terms of the constituents is being found to be of considerable value. The author has used this interpretation since 1904 and has found it of great service in correlating the chemical analysis with the micro-struc-

ture. Since the values for specific densities of most of the constituents of cast iron are now available the composition in terms of the volumetric contents is still more useful.



Structural Composition, in Per Cent, of a Range of Pig Irons from Same Furnace

T.C	C.C.	Gr.C.	Si.	Mn.	S.	P.
3.4	2.8	0.6	0.55	0.70	0.30	0.70
to	to	to	to	to	to	to
3.6	0.2	3.4	3.25	1.10	0.03	0.75

FIG. 1

The application of the method to the composition of pig iron is capable of giving valuable indications to the causes responsible

for the differences in chemical analysis, micro-structure and fracture characteristics. See Figure 1.

A typical illustration may be given of the case of two blast furnaces producing foundry pig iron of similar analysis, the only notable difference in the chemical analysis of the pig irons being in the relation of the combined and graphitic carbon contents. The pigs were of the same section size and the total carbon content was in each case very approximately the same, 3.3 percent. Yet in one case the fracture was regularly open grained and in the other close grained.

Table 3

THE APPROXIMATE CHEMICAL ANALYSIS OF THE TWO PIG IRONS

	T. C.	C. C.	Gr. C.	Si.	Mn.	S.	P.
Open grained iron	3.30	0.30	3.00	1.8	1.0	0.08	1.0
Close grained iron	3.30	0.65	2.65	1.7	0.9	0.10	1.0

STRUCTURAL COMPOSITION

	Open Grained Iron		Close Grained Iron	
	Per Cent Weight	Per Cent Volume	Per Cent Weight	Per Cent Volume
Graphitic Carbon	3.00	9.52	2.65	8.52
Phosphide Eutectic (C-Fe-P)	14.73	14.45	14.72	14.60
Manganese Sulphide	0.22	0.39	0.27	0.49
Pearlite (containing Si and Mn)	2.83	2.58	42.40	39.00
Silico-Ferrite	79.22	73.06	39.96	37.39
	100.00	100.00	100.00	100.00

The author has noticed similar differences in the combined carbon content of British hematite pig irons from the same furnace as influenced by the different cooling conditions during the summer and winter. Apart from the fact that in Britain the wet state of the ore and fuel in winter is conducive to slower reduction whilst the cooler and drier air has the opposite effect, the balance being in favor of higher outputs, it is difficult to trace the higher combined carbon in the winter-made pig iron to anything but the quicker cooling rate of the iron when run into the colder pig beds.

But in the case chosen for illustration the pig irons produced in either summer or winter were characteristically different in fracture as before stated. This is illustrated by Table 3.

From this structural composition of the cooled pig irons it is seen the decomposition of the iron carbide originally present in the molten metal is much more complete in the one iron (0.30 per-

cent combined carbon) than the other. The reason for this difference is not explained by differences in the rate of cooling alone, as might be the case when one iron is cast in metal molds and the other in the customary sand bed, but it is clear that thermal influences must be responsible for the fact, that in similarly constituted sand beds, pigs of similar section are of different hardness. These thermal differences must have functioned within the furnace hearth at the time of casting and before.

The silicon, manganese, phosphorus and carbon contents in the two pigs being alike it may be concluded that the hearth temperatures in both cases were alike, this contention being supported by the fact that the casting temperatures were noticeably similar.

There must therefore have been a difference in the condition of the carbon in the molten metal either immediately preceding or soon after the casting of the two types of pig iron. An examination of the probable molten constitution of the hearth metal is of value.

Assuming that the molten metal consists of the 4.3 percent carbon and the iron-carbon-phosphorus eutectics in which are dissolved the iron silicide and manganese carbide and sulphide the molten constituency of the metal is given thus:

4.3 percent carbon-iron eutectic....70.95 percent by weight

Iron-carbon-phosphorus eutectic ....14.72 percent by weight

Iron silicide, manganese sulphide and iron (free).....14.33 percent by weight

Both irons here are therefore hypo-eutectic, a fully eutectic iron of 1.8 percent silicon and 1.0 percent phosphorus content having a total carbon content of approximately 3.5 percent.

The carbon content of the iron is of course dependent upon the amount of carburization received by the iron in its descent through the preheating zone and, in the zone of high temperature necessary for the alloying of the iron with silicon the iron may easily absorb more than 4.3 percent carbon and become hyper-eutectic and as such flow into the hearth. The action of silicon there is

to graphitize the excess carbon and any metal of this character continues to graphitize during the cooling in the pig beds.

The author considers that this is the mechanism which accounts for the low combined carbon content in some irons. Whenever the carburization falls short of producing 4.3 percent carbon in the primarily melted metal flowing into the hearth the pig iron is likely to have a lower total carbon and a higher combined carbon content than in an iron produced from metal which has been hyper-carburized in the shaft and boshes of the blast furnace.

In actual practice the carburized streams of metal flowing into the hearth must often be mixtures of hypo-eutectic iron. In the large hearth obstructed by masses of coke perfect diffusion of the heterogeneous components of the liquid metal is inconceivable and some irregularity in the pigs run from the hearth must be expected.

The Fracture Index

An intelligent interpretation of the pig fracture, combined with the practice of reading the chemical analysis in terms of the micro-structure is of the greatest possible value to the foundryman and to the responsible worker in puddled iron and steel manufacture.

The experienced puddler in Britain looks askance when he is asked to puddle a charge of iron possessing what he calls a mixed fracture, which is generally of the nature of an open grained structure in which patches of close grained metal are embedded. One part of the metal comes to grain normally whilst the other remains steely and the tendency, unless great care and labor is expended, is for the puddled ball to be uneven in plasticity, composition and weldability.

The author wishes to pay to the intelligent puddler from whom, at the furnace side, he has learned much. In no other furnace can so much be learned of the melting characteristics of cast iron. There the effect of hyper-eutectic iron can be clearly seen during melting and refining—the escape of the kishy carbon varying conditions of temperature and furnace atmosphere—the slow "coming to nature" of the iron as compared with a low car-

bon-hypo-eutectic-iron, and the influence of silicon, phosphorus and manganese on these actions. In the manufacture of wrought iron from pig iron the quality of the product depends on that of the pig iron charged. The average chemical analysis of a pig iron may be apparently satisfactory but if this is the mean hypo and hyper-eutectic metal then there is great danger that the latter metal will cause a lack of uniformity in the final puddled ball, the product of the laborious work of a worker who has been too often despised.

To most metallurgists the mean chemical analysis of a pig of iron is sufficient but this may be the rough average of concentric zones of metal containing from say 0.8 percent to 0.2 percent combined carbon-rings of absolutely dissimilar metal in a structural sense and which, when melted may produce a molten mass of as heterogeneous a character as the initial structure possessed and prone to segregatory habits because of the variable condition and distribution of the carbon, especially when this is changing from the combined to the graphitic form or vice versa.

Knowing as we do the migratory character of carbon, as shown in the processes of cementation, case hardening, malleableizing and graphitization, is it not remarkable that so little attention has been given to the structural homogeneity of pig iron and to the means for producing iron of such regular structure as will, when properly remelted and poured, produce iron castings whose internal architecture shall not need costly methods of heat treatment in order to rearrange a structure which has been primarily confused and segregated in the blast furnace?

The variability of the blast furnace product is recognized by the steel maker where, in mixer processes, the standardization of the liquid cast iron is of such importance. If carbon did not migrate and if, in large molten masses, phosphorus and manganese diffused regularly throughout the metal, the mixer method might find a wider use in the manufacture of high quality castings; but as mass effect plays such a large part in the segregation of the lighter constituents in iron and steel the habit of only melting sufficient metal at a time for the making, separately, of large castings, is likely to persist, for sound scientific reasons.

In the realm of the iron founder and wrought iron worker the problem of obtaining pig iron direct from the ores free from the effects of intimate contact with the reducing fuel and hence controllable in the direction of carbon content and homogeneity of structure, has for years been a cherished dream. In Britain longing eyes have been turned towards such sponge iron processes as have given some promise of practical success and whilst recognizing the technical difficulties attached to mechanically operated furnaces charged with material in agitation, the long and costly experiments carried out in U. S. A. in particular would seem to indicate that ere long the problem will be solved.

Slag in Ferrous Processes

In the three types of pneumatic furnaces used in the iron and steel industry the slags play an important part in controlling not only the composition of the metal by means of thermo-chemical reactions between the constituents of the metal and the slags but by their physical condition as mobile fluids act as absorbers of certain undesirable migratory constituents such as sulphides and gases and, by virtue of their heat conductivity or resistivity may aid or resist heat flow from the fuel or heating gases to the metal in contact.

If the slag composition corresponds to a condition of chemical neutrality, the basic and acid oxygen contents being equal, when functioning at suitably controlled temperatures certain objectionable reactions at the metal surface may be stopped. Thus, in the blast furnace, when the slag becomes neutral the further absorption of silicon from the silica in the slag ceases. Until this point of neutrality is reached the slag, if functioning at a sufficiently high temperature will, if overcharged with silica, allow the reaction between the carbon in the metal and the free silica to proceed, silicon being transferred to the metal. When lime or magnesia are present in excess of the neutral condition the slag, if sufficiently fluid, will absorb sulphur from the metal. Further, such a condition prevents oxidation of iron and manganese for, if lime or magnesia are present in excess of the neutral requirements, the oxides of iron or manganese cannot be absorbed by the slag. Similar actions take place in cupola practice, lime and mag-

nesia in excess of neutral requirements acting as sulphur absorbents at definite temperatures. In this case, however, the slags are too acid (high in silica) to function efficiently and the iron and manganese oxidation proceeds in the direction of neutrality.

Moreover the iron and manganese oxidation occurs at a level in the cupola higher than the position where the slags attain their proper working constituency and requisite fluidity and there is little or no contact of the fluid slag with the metal in the fusion zone. The coke below the fusion zone is then most in contact with the trickling slags and such desulphurization as occurs takes place in the coke and not in the metal. Hence the developments of methods for sulphur removal from the metal by means of slag contact as it flows into or from the well of the cupola.

In the case of the acid Bessemer steel process it is worthy of note that the oxidation of the silicon, manganese and iron proceeds in the direction of the formation of a neutral slag but stops short at a composition which is similar to that of a normal cupola slag, in which the lime is displaced by iron and manganous oxides. Here, as in the case of the cupola, the oxidation of the silicon, manganese and iron takes place in the absence of slag, the oxides formed uniting to form a slag at the metal surface. There is also considerable further oxidation of the iron and manganese which passes off as fume. From the estimation of the metal loss it would appear that a slag of neutral composition is actually formed, part of which is blown away as fume. When melting high manganese mixtures in the cupola there is often much loss in fume and the slag tends toward the neutral condition, iron and manganese oxides being present in abnormally high proportions.

The basic Bessemer process furnishes an example of neutral or inert slags. During the process of the blow the basic oxygen content (in the lime, magnesia, alumina, and manganous and ferrous oxides) gradually increases from 40 per cent of the total oxygen present in the slag to 50 per cent, at which point neutrality is reached. In the basic open hearth steel process a similar transition in the working slags occurs during the melting and refining periods. The slags, immediately after melting of the charge, may consist of oxides containing 65 per cent of acid oxygen. Dur-

ing the progress of the melt the constituency changes gradually from acid to basic, the basic oxygen content of the finishing slags being about 60 per cent of the total oxygen present—the point of neutrality having been passed on the way. In the acid open hearth steel melting process the working slags, by reason of the easy availability of the siliceous material in the hearth lining retain a strongly acid character. The acid oxygen content is high, from 70 to 76 per cent of the total oxygen present in the slag. These slags are interesting from the fact that the composition is often closely similar to that of cupola slags. The pasty condition of slags containing more than 55 per cent silica with 10 per cent lime is analogous to cupola slags of similar composition which function badly and often give troubles in iron foundry practice, being useless from the desulphurizing point of view and liable to affect the fluidity of the metal by encouraging "bridging" or scaffolding and by preventing clean and easy tapping through accretion on the walls of the cupola well.

In the puddling process the slags are chiefly composed of ferrous manganous silicates and phosphates. At the commencement of the puddling the slags are feebly acid. As the "boiling" period is approached the basic oxygen content increases and when the metal comes to grain the slag attains the neutral condition and finally contains excess basic oxygen as a result of the addition of iron oxide, produced during the oxidation of the iron whilst being balled.

Under correct temperature control the puddling process is regulated by the manipulation of the slag composition. The slags are never far removed from the neutral condition and the process is slowed down on the one hand when the slag becomes acid and is hastened when the slag becomes basic. The neutral condition corresponds to a suspension of oxidation or refining during the first part of the process and to a slackening in the rate of iron crystal growth, or coming to grain, in the latter half of the process.

It may be noted that in all ferrous processes mentioned the finishing of the smelting, melting or puddling charges must be carried out in the presence of fluid slags which may be described

as consisting of a neutral matrix in which is dissolved the active constituent necessary either for the alloying of the primary metal or for the removal of the last traces of an objectionable constitu-

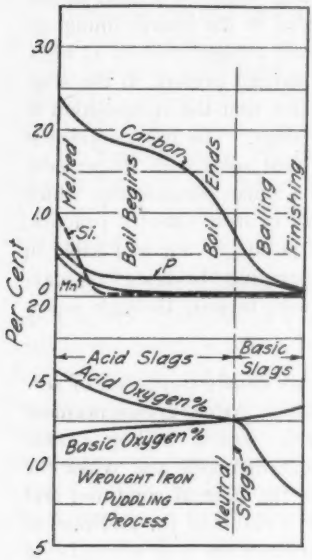


FIG. 2

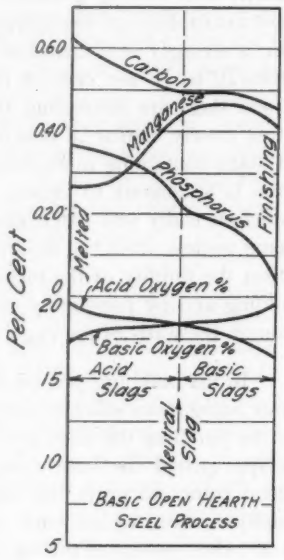


FIG. 3

ent. The temperature at which the slags are held is of course a vital matter and the author attempted to emphasize this fact in a paper read before the British Society of Chemical Industry in 1917 on the superheating of slags and metals during refining, smelting, and alloying operations. The necessity for a mobile fluid condition in working slags was first clearly demonstrated by H. H. Campbell in 1902 or earlier. Campbell's conclusions concerning the fluid condition and the influence of excess basic or acid constituents in the working slags of the steel processes were of fundamental importance and must be considered as the real beginning of practical and scientific research.

In Table No. 4 a summary of the above notes is given and in Figs. 2, 3 and 4, graphs illustrative of the ruling types of slags in the transitions from the meta-stable to the stable neutral com-

Table 4

Process	Nature of First Slags	Inert or Neutral Constituents	Nature of Finishing Slags	Excess Constituents in Slags
Blast Furnace	Acid	$2\ CaO.SiO_2$ $2\ MgO.SiO_2$ $2\ Al_2O_3 3SiO_2$	Basic	CaO & MgO
Cupola	Acid	$2\ CaO.SiO_2$ $2\ MgO.SiO_2$ $2\ Al_2O_3 3SiO_2$	Acid	SiO_2
Acid Bessemer	Acid	$2\ FeO.SiO_2$ $2\ MnO.SiO_2$ $3\ FeO.Fe_2O_3$	Acid	SiO_2
Basic Bessemer	Acid	$2\ FeO.SiO_2$ $2\ MnO.SiO_2$ $2\ CaO.SiO_2$ $2\ MgO.SiO_2$ $5\ CaO.P_2O_5$ $3\ CaO.Fe_2O_3$	Basic	CaO
Acid Open Hearth	Acid	$2\ FeO.SiO_2$ $2\ MnO.SiO_2$ $3\ FeO.Fe_2O_3$	Acid	SiO_2
Basic Open Hearth	Acid	$2\ FeO.SiO_2$ $2\ MnO.SiO_2$ $2\ CaO.SiO_2$ $5\ CaO.P_2O_5$ $3\ CaO.Fe_2O_3$ or $3\ FeO.Fe_2O_3$	Basic	CaO
Puddling Furnace	Acid	$2\ FeO.SiO_2$ $2\ MnO.SiO_2$ $5\ FeO.P_2O_5$ $3\ FeO.Fe_2O_3$	Basic	FeO
Electric Furnace	Basic	$2\ CaO.MgO.SiO_2$ $2\ MnO.FeO.SiO_2$	Basic	CaO

positions may help in emphasizing the points raised. In Fig. 3 the progress of the transition from the acid to the neutral and finally basic condition of the working slags of the basic open hearth steel process is shown.

No figures have been given relative to electric furnace slags but their composition progresses from a feebly basic condition to a strongly basic one, the high temperatures available being sufficient to keep slags of high lime content in the fluid state. Such slags function well as absorbers of sulphur and phosphorus.

The Inter-Relationships Between the Structural Composition of Iron and Iron Alloys

The well known character of the polyhedral structure of wrought iron, dead mild steel, well annealed malleable cast iron and of silicious cast iron when slowly cooled from the molten state and completely graphitized points to the possession by the iron family at large of a common structural basis.

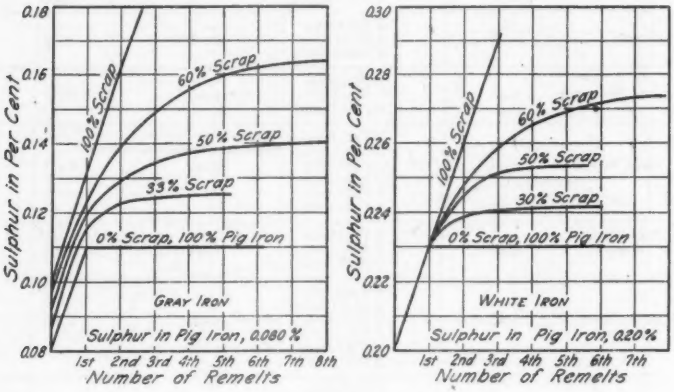


FIG. 4

However masked this polyhedral micro-structure may be as a result of the thermal treatment and of the alloying, more or less permanently, with non-ferrous metals or metalloids it is generally possible to so heat treat the cast or mechanically worked iron or alloy rich in iron as to bring to light the fundamental structure associated with maximum stability.

Underlying these problems connected with metal structure it must be recognized that the outer form of an individual crystal is of secondary importance, the atomic structure as revealed by the exact detail of its space lattice and the disposition of the atoms being incomparably more important. This field of inquiry is being explored but as yet the knowledge of the internal crystal

structure (which is, in most of the technically important metals, of the same space lattice, as modified by the presence of one or more additional metals or metalloids) is far from complete. In cast iron the size of the crystal grain not only varies with the temperature of casting, the mass of which the grain forms a part, and the rate of cooling, but with the metals dissolved in the iron and with the constituents present at the borders of the crystal grains.

If it be accepted that in the molten condition cast iron consists of iron in which is dissolved the carbides, silicides, phosphides and sulphides of iron and manganese, then on slow cooling to the stable condition where the whole of the carbon is in the form of graphite the polyhedral iron grains will be alloyed, more or less homogeneously, with the silicides of iron and manganese, and less homogeneously near the border surfaces with the phosphides and sulphides. In arriving at this stable condition the metal will have passed through the austenitic and pearlitic phases, graphite resulting from the decomposition of the carbides of iron and manganese and finally the phosphide eutectic will have decomposed, yielding iron, graphite and iron phosphide. The size of the final iron grains is conceivably controlled by the amount of supercooling which occurs just before solidification of the molten metal commences, the rate of crystal formation being dependent on the degree of supercooling and on the viscosity of the metal during crystallization. This viscosity is not independent of the metal mass and is influenced by the presence of foreign constituents dissolved in the iron. Hence it may be safely concluded that the size of the final stable crystal grains in a slowly cooled cast iron are influenced by the silicon, manganese and phosphorus present in the molten metal. Any modification in the growth or shrinkage of the nascent crystal grains, as the metal is cooling through the critical change points associated with the passage from the gamma to the beta and alpha iron conditions, must be influenced by the presence of silicon, manganese and phosphorus in the iron.

In cast iron the contents of silicon, manganese and phosphorus in the final stable grains will approximate to the values determined by the chemical analysis of the cooled metal. The in-

fluence of the heat liberated during the graphitization of the primary iron carbide and of the gases liberated during solidification, some of which are entrapped within the solid metal, cannot be ignored. Both these liberations are accompanied by volume changes and have an influence on the growth of the cooling crystal grains.

In the case of steel the lower carbon and silicon contents in ordinary straight carbon steels do not appreciably influence the grain size during slow cooling but if the cooling is exceptionally slow and the metal mass great, graphitization of the primary iron and manganese carbides occurs and the final stable structure is polyhedral-grained, the grain sizes being similar to those produced in cast iron of similar mass when cooled at the same rate. Here the graphitization follows the grain boundaries as a result of the decomposition of the carbides whilst slowly cooling through the temperature range above 100 degrees Cent.

In the manufacture of puddled iron the iron grains are formed primarily during the supercooling of the alloy on the borderland between cast iron and steel (1.8 to 2.0 per cent carbon). The grains grow rapidly and have envelopes of very pure iron. The centers of the grains, or clusters of grains, are richer in carbon than the outer envelope. The squeezed plastic mass of puddled iron is composed of crystal grains of similar form and often of similar size to those associated with the structure of slowly cooled cast iron. The grain size in puddled iron is influenced by the manganese, silicon and phosphorus content of the pig iron from which the iron is made and, in some cases the original carbon content of the pig iron appears to play a part.

Puddled iron may therefore be considered as being the result of slowly cooling a cast iron through the higher temperature ranges, the carbon, silicon, manganese, and phosphorus being removed by oxidation during the liquid and plastic ranges. The gradual reduction of carbon during the plastic period is equivalent to the graphitization and decarburization which take place during the malleable white-heart process. The two final and stable structures are remarkably similar both in the form and size of the polyhedral iron grains—in the wrought iron and in the completely

decarburized areas of the malleablized cast iron. The coincidence of low manganese and silicon content in similarly grained wrought iron and malleable cast iron should be noted.

In the foregoing notes, stress has been laid on the stable character of completely graphitized cast iron, steel and malleable cast iron; wrought iron being placed in the category of a slowly cooled cast iron from which the carbon is removed by oxidation mainly during the semi-solidification of the virtually cooling metal, there being no pearlitic range during the transition.

This stable condition of approximately ferritic metal, calls attention, logically, to the fact that, when cast, pig iron or steel-containing combined carbon, is of unstable structure. The transition constituents austenite, troostite, martensite, sorbite and pearlite in cast iron, malleable cast iron, and steel are relatively unstable in comparison with wrought iron and dead mild steel. To ensure the maximum stability of a steel containing a mixture of constituents a suitable heat treatment is necessary in order to homogeneously mix the constituents. In grey cast iron of normal composition the constituents are never homogeneously mixed as ordinarily cast; owing to the differential rate of cooling from the outside to the inside of the mass. Hence the attempts now being made to regularize the structure of cast iron by approaching a structure which is completely composed of pearlite and graphite.

A careful examination of a homogeneous pearlitic structure in cast iron shows that the pearlite occurs in polyhedral grains of similar contour and size to those which would result from slow cooling the cast iron, after reheating to the melting point, to the point of complete graphitization. This pearlite filled grain structure is evidence of the effectiveness of the cooling rate which has produced it and of the stability of this type of pearlite. Experience has proved that confused structures in the pearlitic areas of steel or cast iron are indicative of internal strained conditions, the result of unequal rates of cooling within the mass. These heterogeneous structures may be connected with the imperfect diffusion of the various ingredients of the charge as melted in the cupola or open hearth furnace.

Much remains to be done in the study of grain size in cast iron, wrought iron, malleable, cast iron, and steel but there is much that suggests the possibility of the original grains, as formed during the solidification of the casting or ingot, retaining their form within the metal mass, masked though their boundaries may be by later reheating and the break-up of the internal structure of the grains. This suggestion receives support from the fact that an originally coarse grained iron may be so heat treated as to break up the structure and destroy, apparently, the primary grain boundaries. Yet, after reheating to near the melting point and slow cooling the large grains reappear, being copies of their former selves. Perhaps they never actually lost their entity, but were masked by the thermal treatment which only broke up the crystalline structure of their interiors.

The Scrap Problem

The difficulty of estimating for any country, with any degree of accuracy, the percentage of scrap produced in terms of the tonnage of pig iron, iron castings, steel and iron rolled, forged, stamped and drawn material, and of steel castings and ingots, per annum, is admittedly great; but in order to get even a rough idea of the trend of manufacturing methods the function of scrap in ferrous processes must be visualized.

The very considerable amount of steel and iron used in structures and articles having short life through wear and tear, oxidation, corrosion, irrecoverable loss through shipwreck and accident is increasing yearly. The changes in engineering practice, causing machinery to rapidly become obsolete, particularly in the marine, railway and road traction, electrical and chemical engineering branches, are responsible for the return to the iron and steel works of scrap at a rapidly increasing rate. To this the return of war scrap must be added, together with the scrap from the demolition of out-of-date factories and plants.

Altogether it will be seen that at the present time, in order to use up the bulk of scrap available and to prevent its too rapid loss through corrosion alone, the mixtures for steel furnaces, foundry cupolas, and wrought iron scrap furnaces must contain

increasing percentages of scrap. The growing use of direct metal from the blast furnace to the steel furnace throws a larger scrap proportion upon the remaining furnaces using solid charges.

One, if not the greatest factor in this scrap problem is the effect now being felt in pig iron production. The temptation to use scrap of a nature unusable in steel and iron melting furnaces, as additions to the ore charges in blast furnaces, cannot be ignored by the foundryman, who is often puzzled to know the reason for abnormal happenings in his castings.

The difficulty of assorting scrap in these days and of judging its character by appearance alone, chemical analysis being in many cases impracticable, constitutes a serious danger. The fluctuations in the scrap and pig iron markets cause alternations of runs on either scrap or pig. As a consequence the quality of the cheaper grades of steel and iron fluctuates. The tendency is for good quality scrap to be scarce during certain boom periods and the poorer qualities to accumulate. Then follows a harvest of poor steel and iron products, the result of the temptation to use cheap scrap; for, obviously, the scrap seller can always drop his price so as to cut out pig iron competition.

The greatest sufferers from these scrap fluctuations are the foundrymen and wrought iron manufacturers for, wherever these cannot supply their own scrap needs so-called "foreign" scrap has to be purchased.

It is clear that if metallurgical control is necessary even when using the best of available ores and pig irons, in order to guarantee high quality "safety-first" iron or steel, such control is almost hopelessly impotent when from a third to a half the furnace charges must consist of scrap of doubtful character.

In the blast furnace not too rarely, the charging of mixed cast iron and steel scrap, iron and steel turnings, bundled detinned sheet and clipping scrap, to name a few of the odd materials which, generally unusable elsewhere, has resulted in a mixed varity of pig iron of most uncertain quality, the scouring of the scrapyards of Europe.

The skill of the most expert metallurgist would be baffled were he to attempt a forecast of the pig iron composition and

structural analysis made from burdens of this character. When, in addition, coke of variable sulphur and ash content has to be charged the position of the foundryman or iron worker who may have to remelt such pig irons (which have not infrequently been sold in Europe as refined irons, after being run through a cupola as a mixer) may be better imagined than described.

In order to safeguard his product, the wrought iron manufacturer who values his reputation has had to make his own scrap from puddled material of known character.

In the steel works the growing use of high scrap proportions in the furnace charges has also had its dangers. It has been exceedingly difficult to keep out of the mass of bought scrap metal containing unexpected alloyed materials such as nickel and chromium. Batches of high sulphur and high phosphorus metal occasionally drift in mysteriously without warning.

The gathering of scrap ferrous materials into specific areas where it can be systematically dealt with is occupying the attention of many metallurgists and some attempts are being made to accumulate cast iron scrap at convenient points where it can be remelted and disposed of as scrap pig iron. Unless a careful system of chemical analysis is employed at these scrap centers, whereby a check on the composition of the remelted products is assured, trouble for the user lies ahead.

In the interests of the iron and steel industries this matter demands serious attention. The disposal of scrap cannot be allowed to remain in the hands of distributors who are careless and often ignorant of the scientific importance of the problem.

If well handled the whole scrap problem in any country could be satisfactorily solved and the metallurgist freed from the uncertainty he so often feels when dealing with unknown scrap.

The blast furnace, as a remelter of iron and steel scrap, may possibly be one means of economically dealing with part of the problem.

The cupola has clearly much scope in remelting odd casting scrap, whilst the open hearth furnace may be used as a re-

melter of heavy scrap, and the electric furnace as a desulphurizer of such metal scrap as would tend to become useless.

To each country whose interests in ferrous metallurgy are vital, the scrap problem must become one of national importance. It seems to the author that the time has come for serious action, for a scientifically operated control in the interests of the iron and steel industry. The foundry organizations and institutions might take up the consideration of this question with great advantage to their industries and symposiums of papers dealing with the various aspects of the scrap problem would be of great value.

Much remains to be known concerning the influence of repeated remelting of iron on the structure of the product, as compared with the remelted virgin pig iron structure.

Every foundryman has his own conception of the value of certain proportions of casting scrap in his mixtures and, as a consequence, cupola charges vary between all pig and all scrap mixtures. How do these variations affect the structure of the product, apart from the pure chemical analysis of the ingredients of the charge and of the resulting castings?

Much has been said about the so-called inherent properties of certain brands of pig iron, the use of which is often associated with good castings. In Britain all-mine pig irons are sought for because they balance the evil effect of scrap metal which, by repeated remelting, has passed a possible critical point where its structural composition has begun to deteriorate rapidly. There is of course a partial explanation in the chemical analysis of the virgin pig iron and of the repeatedly remelted scrap, but the modification of the chemical analysis produced by varying the percentages of virgin pig iron and scrap does not always represent the differences produced in the mechanical properties. These differences are related to the structural composition of the metal and to its degree of homogeniety.

In cupola melting for example the size of the scrap and its relative bulk in the pig plus scrap charge often plays a very important part, just as the mixtures of fine and lumpy ore in the

blast furnace burden may influence the character of the pig iron even when the chemical composition of the powdery ore and of the ore lumps is similar.

The consideration of the effects of scrap percentages in a cupola or air furnace charge results again in the conclusion that the structural composition of the product is the all-important question. It would appear that homogeneity of cast structure is the index to the quality of irons of similar chemical analysis and of similar mean constitutional analysis.

Just as the bulk analysis of molding sands of very different grain size constituency may be closely similar, so the mean chemical analyses of cast irons of greatly different grain size and structural homogeneity may be approximately or closely alike. Taking the molding sand illustration again it may be noted that just as the addition of new sand to used floor sand in proper proportions enables a sand mixture to retain its properties so the use of virgin all mine pig iron in correct proportions in a pig iron plus scrap charge serves to regularize the structural properties of the cast product and to reduce the deteriorating influence of the added scrap. In both cases there is a time limit and a critical number of mixings beyond which the used sand and the scrap contents of the mixtures begin to deteriorate seriously.

As an illustration of the sulphur influence in deteriorating English white-heart malleable, the result of repeated use of scrap from preceding melts, the graph Fig. 4 is given.

In the same diagram the sulphur deterioration during the cupola melting of pig iron containing 0.08 percent and scrap containing 0.10 percent sulphur is given. In each cast the scrap used is assumed to be taken from the preceding melt, the sulphur addition per melt being estimated as 0.03 percent. In actual practice of course the scrap produced is not sufficient for the succeeding melt and foreign scrap has to be purchased. If the latter could be guaranteed to contain as low a sulphur content as the pig iron the scrap from the succeeding melts would increase much more slowly in sulphur content and it would take longer to reach the danger limit.

The curves indicate clearly the approximate number of remelts required to reach the point when further remelts do not add much sulphur to the cast products. The maximum sulphur content is reached more quickly as the scrap percentage in the cupola charge increases.

By the same method of attack, the influence of scrap proportions on grain growth in the metal cast from similarly remelted pig iron and scrap mixtures is capable of determination.

The oxidation of the iron, silicon and manganese can also be progressively traced in relation to the number of remeltings and pig plus scrap proportions in the charges.

In conclusion, the author wishes to express the thanks of British foundry research workers to their American colleagues for the interchange of information on foundry problems which have done much to encourage the advance of research in Britain.

In particular the British Cast Iron Research Association is grateful for the many research and allied publications dealing with ferrous processes which have been so willingly sent to them from the United States of America. The proceedings of the American Foundrymen's Association are always looked forward to by the members of the Institute of British Foundrymen, and the opportunity and honor of being able to present exchange papers from time to time is highly appreciated by all connected with the British Institute and the Cast Iron Research Association.

WRITTEN DISCUSSION

R. S. MacPherran, Allis-Chalmers Mfg. Co., Milwaukee.

It was with great pleasure that I read the paper by J. E. Fletcher on the relationships between cast iron, wrought iron and steel. It is most encouraging to note that the problems of cast iron are, at last, receiving the same attention which has long been given to those of steel.

Referring to the paragraph toward the end of page 15, in which the author speaks of patches of close grained iron mixed with those of coarse grain, I would ask if the author has ever polished off the entire face of the pig and compared the microstructure of these various grains, and if so, how did the struc-

ture of the close grain spots differ from those of the coarse grain? In past years, when we were using a sand cast pig, I have often noticed this peculiarity, more especially in irons which were fairly low in silicon, but at that time we had no microscope available, and so were unable to make any structural examination. Chemical analysis fails to reveal any striking differences. Most of our coke irons are now chill cast, which condition makes much harder any study of this peculiarity.

In the author's discussion on page 15 of the chemical analysis of two pig irons of unlike physical properties, we would be interested in his opinion as to why they were so different in their combined carbons. What were the cooling conditions? It would also be interesting to know whether any determinations other than those ordinarily made were attempted. It is always possible that enough of some rare metal might be present in sufficient amounts to affect the combined carbon. On page 4, the author refers to the difference between two pig irons, one made from an ore rich in iron and in a fast driven hot blast furnace, the other pig iron made from a lean ore in a slow driven warm blast furnace. We would be pleased to hear whether he has ever made comparative physical tests from such pig irons and what results he finds. Also what physical properties each iron would be apt to transmit to the castings made from it.

Referring to the discussions on pages 29, 30 and 32, on the subject of the effect of adding steel scrap turnings, bundled sheet, etc., to the blast furnace charges, would say that this practice has been under discussion for the past year in the meetings of our committee for Gray Iron Castings, and we have recommended to the American Foundrymen's Association that a committee be appointed for the purpose of investigation of these effects and for the study of blast furnace practice in general, with the idea of determining its effect upon the quality of the pig iron produced.

In closing, I wish to say that the American Foundrymen's Association is to be congratulated on having a paper of this scope presented, and I feel that the author is entitled to the thanks of the association for so ably bringing out some of the many problems of cast iron.

DISCUSSION

CHAIRMAN A. H. JAMESON: The world moves. It was not so many years ago when, if an industrial organization wished to learn something about what a competitor was doing, it had only two ways of doing it. One was to crawl over the fence or under the fence and the other was to have someone disguised as a workman get a job in the other fellow's plant and come back with the sketches, if possible. Today we are exchanging ideas on the general principle that we are getting more than we give in every exchange. Here we have many associations, large and small, who spend all their time collecting such information and disseminate it among their membership. The time has passed long ago when anyone has cause to distrust the information he gets from his neighbor. The same thing is true abroad. The British Cast Iron Research Association and the British Wrought Iron Research Association, as examples, are fostering research in the ferrous metals. The expenses are paid in half by the membership, largely by the bigger concerns who are interested but who, themselves, are benefitting less than the others because thy have their own research organizations and staffs, and the remaining half of the expenses are paid by the British government with an enlightened look forward that we can very well copy. Now, for several years, we have gone a step beyond the local exchange of knowledge and we have been exchanging our ideas with our British cousins and brothers. Each year now the American Foundrymen's Association and the Institute of British Foundrymen exchange their thoughts, their ideas and their suggestions by the interchange of papers. This year we have a paper on some inter-relationships in cast iron, wrought iron and steel practice, and it is with pleasure that I introduce Mr. J. E. Fletcher, consultant for the British Cast Iron Research Association and the British Wrought Iron Research Association, who is to deliver this exchange paper. Mr. Fletcher.

J. E. FLETCHER: I thank you, Mr. Chairman and gentlemen; I thank you, Mr. Chairman, for the very kind remarks concerning exchange papers, which I think has been valued very highly on our side of the Atlantic. I feel particularly the honor of the present occasion and of your welcome given to me as the British representative on this occasion.

We in England have been finding for some time that we needed to come into closer touch with every department of research. We are striving now, as far as we can, to increase these points of contact, not simply by giving papers but by sending someone in person to actually come in contact with our friends in various parts of the world.

I feel that it is a great honor to be asked to give this paper. Although it is at some considerable inconvenience as a busy man and at some expense at this particular time to come over to America, yet I felt that I should be benefited and that our relationship would be all the better if, following the example of my good friend, Mr. F. J. Cook, who came over here some years ago, I should follow after him. He, if I may be permitted just at

this moment to say it, and many others on our side who have met some gentlemen who are in this room, who have visited us, commissioned me to send the good wishes of our English foundrymen to you, our American brothers. This contact that we are striving to encourage has recently been followed up by visits on behalf of our research association to Germany and France and Belgium, as we are realizing that this method of attack is of very great service to our research association and to its members.

The paper that I have prepared has been written with a view to making certain suggestions with respect to the direction in which research on our side is moving, and with the hope that such suggestions may be fruitful both here and elsewhere.

CHAIRMAN JAMESON: Gentlemen, the exchange papers that we get from the Institute of British Foundrymen are always stimulating and always full of interest. Our British friends do nothing by halves; when they send an exchange lecturer they send their best, and British best is second to none. I am sure the paper which Mr. Fletcher has read is one which will cause us all to think a great deal. The paper is now open for discussion. I am going to ask Dr. Moldenke if he has anything he would like to say or ask.

Dr. R. MOLDENKE: This paper gives us lots of food for thought, in fact, there is so much in it that it is very difficult to discuss it. I know I had to read this paper over about six times before I got the import of the many points brought out in it and I can only give an impression of the paper as presented. We are particularly happy to have a paper from a man who is not only a foundry man, but a blast furnace man and a puddler. Most of us are acquainted with one process but not the other, but we have here a paper by a man who knows all those angles of the iron industry and consequently can write about them very nicely.

The paper brings out the point that the problems of the British foundrymen are very different from those we have. Their blast furnaces turn out two or three hundred tons a day, while here our blast furnaces turn out a thousand tons a day, so that the viewpoint of the two will naturally run apart, and we are very glad to get their viewpoint.

One thought brought out that pleased me very much is that we can learn from the British the metallurgy of various branches of that industry and also the metallurgy of the other metals. There was very well brought out the question of pig iron scrap, the various oxidizing conditions, etc. I feel myself that I would like to divide the iron as the foundryman has it, into really two classes, the class which has not been oxidized in the blast furnace, the virgin metal, and the material which has been oxidized and re-melted. The two are so different in their effects. Yet, when we see what the difference is, we Americans do not realize the significance of the physical structure so much as Mr. Fletcher has brought out. We have gone through the fracture question and do not want much

to do with fracture, but we want the analysis more. Now I feel that the analysis of iron does not mean everything, as Mr. Fletcher has brought out, because the analysis of iron as we have it, is not the complete analysis; we know that there is ferrous oxide dissolved in iron, but our analysis does not show it. There are many things perhaps to be learned yet from an analysis of iron which will give us more information as we go along.

I was particularly interested to see the report of the last meeting of the German Foundrymen's Association. I noticed there three papers on the finding of oxide of iron dissolved in iron by chemical methods. That is progress. The Bureau of Standards have been working a long time on finding an easy, quick and accurate method for determining the per cent of oxide contained in iron. If you deal with boron, you will learn that a thousandth of one per cent of boron has a wonderful effect. I believe that in ten or twenty years from now we will know a great deal more on this subject. Our American viewpoint is rather in the direction of laying more stress on the chemical analysis than on the physical structure because, well, let us say our pig irons are all bad as compared with the English irons.

The question of microstructure was brought out in relation to pig iron, but we feel that if you are going to melt it afterwards the microstructure does not mean so very much, because, after you melt it, something happens to change the structure. Perhaps Mr. Fletcher will give us a little more light on that subject.

The very nice exposition Mr. Fletcher has given of the points that occur in the blast furnace that have to be watched were, to me, highly interesting, because you could see that every one of those points has an effect on the ultimate pig iron made. When you go into blast furnace plants and see the trainloads of scrap coming into the yards, you wonder what our foundrymen are getting in the way of pig iron. The thought expressed at the Milwaukee convention and further here, that we foundrymen should see if we cannot develop some standard of pig iron so that we will know what we are doing, is going to be a good thing.

Those points that Mr. Fletcher brought out all center in this idea, that the ore charge must be given a chance to be perfectly reduced; in other words, we do not want any ore to come down in the bottom of the furnace unreduced, as oxide of iron gets in the way of unreduced ore. Down in the bottom of the blast furnace, as Mr. Fletcher brought out, there is a chance for re-oxidation of the metals on the inside.

The sum of the whole thing, as it appears to me, is that there is not only room for a cast iron research association, and our British friends have outstripped us in that, in this country, but there is tremendous room for a blast furnace research association and I hope some day that will come.

J. E. FLETCHER: I realize of course that there is a great difference between our practice and yours, and it was because of that that I brought

this forward, thinking it might be of some use to you, who some time think our methods entirely behind the times. While we have not the same output as you have nor is there that demand, so far as quality iron is concerned, we hold very strongly the opinion that our smaller furnaces make the best iron; in fact, most of us who are in the trade could count on the fingers of almost one hand or at any rate on the fingers of two hands, those furnaces that we rely on for our best foundry iron. I might say that in every one of those cases, those furnaces are producing only comparatively small amounts of iron and the blast temperatures employed are low. I think Mr. Cook brought that out in his paper some time ago, but I brought in the case of wrought iron. This I did because we have found in the manufacture of wrought iron that even more than in the case of cast iron, gray iron, that the difference in the quality of the iron is reflected in the quality of the wrought iron produced. I have had some correspondence and communication with American wrought iron manufacturers, and they have the same experience. Many of them, whom I have seen recently, were using iron of the same character that we like to use when we can afford it. At the present time, as you know, the English iron industry is in a very poor condition and there is a temptation to use these lower class irons. We are not making anything like the good iron that we were while our furnaces were running regularly and with better ores and better conditions generally.

Dr. Moldenke also called attention to a question of fracture analysis. Of course I am not trying to bring back the old desire to rely upon fracture at all, but the fracture does to some extent and must convey to the blast furnace man an index as to how his blast furnace is working. I might mention here that an old puddler will not work with what he calls a mixed fracture. The curious thing about it is that if he works that iron in his furnace, the iron does not melt or reduce regularly, a portion of that pig will come down and begin to form a ball before the rest of the pig. Although you may have other pig from the same charge which is uniform in fracture, yet if you work it with the un-uniformly fractured pig, the manipulation of that pig under the tool in the puddling furnace is entirely different from the other. I have known men to go out and throw down their tools and say they will not work unless they have the uniformly fractured iron. The fracture as related to what we are finding in steel is a very important way of making an examination now, that is, a study of the macrostructure, rather than of the microstructure. We are trying to develop a method of showing the macrostructure of cast iron. We are trying to go a little further and see whether we cannot get a macrostructure like a sulfur print from it that will give us a further index as to what the actual physical character of the iron is as compared with its chemical analysis.

I was interested to hear those few remarks about boron. I have had some experience with boron in steel. I succeeded in making a very strong steel by using a very little boron in it. So far as I know the only

available boron deposits of any value are on this side, so I hope that our American friends will show us something more along that line.

I entirely agree with Dr. Moldenke that we want to know a great deal more about the oxygen content of cast iron. I had the pleasure of going into that matter pretty carefully with professor Piwowarsky and other German workers three months ago, and they are at work very hard on this particular subject and they have gone a long ways. I believe the next six months will bring forth literature that will amaze not only us in England but you in America. The work being done in Germany is simply magnificent, and all those men who are at it are convinced that it is going to have a very important bearing on iron and steel manufacture. It was not only the men who are at work in these technical high schools but also Dr. Strauss and other men who are in Krupp's Works who are of the same opinion, that it is going to be of vital importance in the future in the making of quality iron and steel.

At this time I would like to reply to the written discussion by Mr. MacPherran. The points that Mr. MacPherran has brought out are very important. I do not know whether I can straightaway give him answers, but as far as the two pig structures that he referred to, especially the one containing what we call a mixed fracture, we have had the same difficulty. We have tried to find out differences in the chemical analysis in these various batches and in the surrounding or normal metal but we cannot find anything there, even though we have tried scores and scores of times. We have also taken micrographs over the whole of the polished pig time after time, but this is one of the places where micro-examination seems to fail. We are at best only exploring, just point by point, over a section, and we have not even been able to find there any great difference in the structure.

This brings us back really to this macro-examination, and there the llittle we have done on these scattered fractures is beginning to bear some fruit. There is a difference in the macrostructure, but apparently no difference in the microstructure. A macrostructure of course is simply the structure by magnification of five diameters instead of three or five hundred. It is just at four or five diameters that you begin to see something that is understandable to the mind and observable to the eye in many cases where the microscope itself fails to give us anything more than just the small view of the wonderful main constituents.

The other point, the physical properties of those two irons that were made from the same furnace having the same chemical analysis but different grain size or different microstructure—there was of course a great difference in the physical properties of those two irons. The one which was nearest to the pearlitic structure was of course the stronger iron. Those two irons, when re-melted, copy, in a sense, their original characteristics; that is, the iron that was really pearlitic remains pearlitic constantly from that furnace. That is a furnace I have a particular con-

nection with and from that furnace continually the iron is always of that type; yet, from the other furnace we always get the open iron. One iron will break immediately and the other will take five or six blows before it will break. Our men at our foundry immediately know whether they have got the one pig or the other. When the iron is re-melted and we make charges from that pig iron we get the same kind of difference; one is a strong 15-ton or 16-ton iron whereas the other is constantly somewhere about 12 or 13 ton. We are not yet able to say why that happens, but in the English iron we find it continually. There are five or six furnaces in our country producing iron of that character, which always gives the same results. Of course it leads us into putting a little white iron into our mixtures occasionally, and the curious thing is that if you put white iron into the mixture, it strengthens it, although you get the same chemical composition. The addition of white iron to a mixture, which is not unusual in our English practice, sometimes will keep up our combined carbon in the castings and give result in the castings we want. That is a very difficult problem for the purely chemical metallurgist to answer.

DR. R. MOLDENKE: What you said just now about open and closed iron is to me very interesting. It makes me believe that this comes right back to proper gating. In other words, suppose you pour your casting and the metal sets there so that you get the skin formed and it cannot feed any more. Does not that mean open and closed structures inside that iron? Or let us say this, that the iron is so very, very good that it remains liquid a long time and the feeding is frozen off. I have repeatedly had to tell the people in foundries, "Your iron is too good for your work, it is so good that the iron is liquid a long time and the gates freeze oil and you cannot get any more iron in. You have to open the structures; put more scrap in the iron and it will set faster inside before it freezes and you will get a stronger iron. In the case of good, well-made iron the setting point is so much lower than in the case of the other, that it makes a difference in the structure. Foundry practice comes down to three things, good material, good processes and good gating of the mold. I wonder whether that hasn't something to do with it?

J. E. FLETCHER: I think so. Of course you, in this country, are making most of your pig iron in chilled molds; at any rate, you are not casting sand pigs any more. Occasionally we water liberally on top of the pig iron and we thought that was the reason for our scattered fractures. We found occasionally that scattered or mixed fractures were associated with that sort of practice, but we have not been able to say that thas is actually the cause. I do believe, however, that if you cannot feed a casting properly it does affect the structure internally.

There is another point I brought out, the question of the viscosity of iron in the liquid condition which we are examining now by various methods. It is a difficult problem, but there seems to be something there

that we know very little about. The viscosity of an iron has a great deal to do, we think, with the fracture of the resulting cast metal.

J. T. MacKenzie: In calculating the structural composition of the two cast irons (page 11) Mr. Fletcher assumed that the phosphorus is all present as the ternary eutectic of phosphorus, carbon, and iron, which is in accordance with the findings of Goerens and others. Stead says that in gray cast iron this ternary eutectic is decomposed, giving steadite, which contains 10 per cent phosphorus and 90 per cent iron, all of the carbon of the eutectic going to form graphite or pearlite. Sauveur worked out the structural composition of gray iron on this basis. His calculations applied to Mr. Fletcher's iron would give percentages by weight as follows:

Open Grain—Pearlite, 36 per cent; Ferrite, 51 per cent.

Close Grain—Pearlite, 78 per cent; Ferrite, 9 per cent.

To check the two methods of calculation, I took a sample of a pipe made in our plant which was practically pearlitic throughout, showing only steadite, pearlite and graphite, after etching with picric acid, and examined at magnifications ranging from 30 to 300 diameters. The analysis showed 3.6 per cent total carbon, 0.7 per cent combined carbon, 2.9 per cent graphite, 1.5 per cent silicon, 0.06 per cent sulphur, .04 per cent manganese, and 0.8 per cent phosphorus.

The ternary eutectic calculations would call for pearlite 56.4 per cent and ferrite 27.5 per cent; the phosphide calculation would give pearlite 84.10 per cent and ferrite 5.1 per cent, which is certainly much nearer the truth than the first. I bring up the subject, first to show that our iron does not form the eutectic, and secondly to find if the British iron does. I do not believe that the analysis of an extrusion is sufficient evidence, for there are many changes in structure after that thermal point is past. Did you arrive at your structure by calculation, or microscopic observation?

J. E. Fletcher: These are calculated values.

J. T. MacKenzie: I am glad Mr. Fletcher brought out the point on the study of viscosity, which is being made by Oberhoffer in Germany also, but there is another property of cast iron that I should like to see studied, which would be practically impossible for us industrialists, and that is the specific heat of iron above its melting point. Take what the foundrymen call quick setting iron; what could that be but low specific heat? Take irons in identical ladles at 1400 degrees Cent.; one will drop to 1200 degrees in five minutes and the other will require fifteen minutes to drop that much—what could cause it but a difference in specific heat? A high carbon, high silicon iron should have higher specific heat than iron low in these elements, but a quantitative study should certainly be made.

We all appreciate the cooperation of the Institute of British Foundrymen, but I cannot forego the opportunity to challenge the policy of

the British Cast Iron Research Association. This association not only excludes all but British subjects, but it does not even give its associate members, into which class I should fall were I a British subject, the benefit of its researches. They are given to the manufacturers only as a closed group. I do not like this ancient idea. I am a member of the Iron and Steel Institute (British) and am very proud of that membership, which has been of great benefit to me. It does not seem fitting that the Cast Iron Research Association should adopt a policy of confidential research.

J. E. FLETCHER: Mr. MacKenzie's remarks are very much to the point. We also have been studying this question, both from the standpoint of iron with respect to phosphorous, whether phosphorous in iron, the gray cast iron, is in the form of the phosphide eutectic or in the form of steadite. In our country we rather take the German view, that it is a carbon, iron, phosphide eutectic, containing about 7 per cent of phosphorous. That is the eutectic. We have had many cases brought before us of the defective castings where the base of the eutectic has been thrown into the field of the specimen and those fields have shown up in many cases just the pure carbon iron phosphide eutectic, rather than steadite. We do not want to be too dogmatic about that yet, but at any rate, as far as we can see, our method of taking this phosphorous present as in the eutectic seems to work out satisfactorily. Of course the volumetric analysis does not show the micrographic analysis. The micrographic analysis might be taken, as Dr. Sauveur calls it, entirely in proportion to the volumetric analysis of the metal, or it may be that is not quite the proper way of taking it. So that what Mr. MacKenzie said about this volume as related to the microscppic area may not be quite correct, although we know that is the view of Dr. Sauveur has taken.

Regarding the question of viscosity and specific heat—we are following that up and Mr. Oberhoffer is at work on that question of specific heat also. There is no doubt some vital connection must be between specific heat on superheated liquid iron, and the viscosity. It may not be though that the is the only factor. We think that there are other factors at work and it may be that in cast iron the oxide of iron factor is perhaps the most dominant. We have a lot to learn with respect to that yet.

I was interested in the criticism of our work as a research association. I want you to understand that our research association was born during the war, and that it was concerned at that time with processes which were not entirely of such a character as might be thrown out world-wide. Our engagement then was for a certain period of time under which we should operate and during that time I suppose legally we must work along those lines, but perhaps after that period has been exceeded, we shall be able to broadcast our work much more so than at present.

We must realize that our manufacturers in England have given millions to the research programs of our various associations, and we feel

at any rate until our term of office is filled, that we must keep at any rate some of our information for the benefit of our members only until that time comes. Now we are issuing more or less a generally useful sort of information which we can broadcast, but our manufacturers are very conservative in England and say, "If we pay you for this sort of research we should own it," and at present we have to obey their dollar.

R. F. HARRINGTON: One or two thoughts along the line which Mr. Fletcher pointed out, namely, the fact that chemical analysis alone, as chemical analysis stands today, is not a true criterion of what we may expect in iron. It was my pleasure some time ago to prepare a paper on the question of the manufacture of old cast iron guns. In my endeavor to get data for that paper, I had occasion to go through a great many of the government records on the manufacture of those cast iron guns from the metallurgical standpoint. I think that possibly, gentlemen, we can take a little page from the note books of these very able engineers and metallurgists who developed the big 40 ton cast iron gun previous to the Civil War, when they did not, by any means, have the material to work with that we now have or the knowledge. In practically every instance an officer of the U. S. Army was detailed at the blast furnace when the blast furnace was producing iron for these big heavy castings which were to be later on the pig iron which was to be later on melted in a so-called air furnace I invariably found that these reports covered the report of the officer at the blast furnace on the working of that blast furnace. In other words, possibly if we visited our blast furnaces a little more frequently, it might be to our distinct advantage. It was found in those researches in the manufacture of cast iron guns, that a great deal was dependent upon the working of those blast furnaces. It was shown that the failure of many of those guns was attributed to the fact that the blast furnace metal was inferior in the one case as compared with the other, purely from the standpoint of incorrect operation of that furnace. It was interesting to note that in the case of one blast furnace operator he operated on a hot blast until he saw the officer coming around the corner, and then he changed over on to the cold blast while the officer was there. The point, however, I am bringing up is this, that these men who so very ably developed cast iron for our heavy guns previous to the Civil War recognized the importance of careful metallurgical practice at the blast furnace.

During the past two or three years there have been many engineers who have gone on record as not desiring any steel for their mixtures in certain classes of heavy work. Theoretically if the two irons had the same chemical composition, meet the same physical test, Brinnell, etc., there would seem to be very little reason why steel should be kept out of the mixture, but very able engineers from a purely operating standpoint have gone on record in their desire to keep steel out of the mixture. Discussing this matter with Mr. Fletcher, I asked him the question, and

he said that he preferred to keep steel out of the mixture where it was going into a heavy section. Now, then, we cannot explain why these engineers have arrived at this conclusion; I merely offer it as a thought that possibly we have failed to obtain from the chemical analysis we now perform and from the physical test we now perform, all of the true facts of the service rendering ability of a particular iron.

Dr. Moldenke has pointed out that our chemical analysis has to be carried possibly a great deal further. Then with our greater knowledge obtained of the gases contained in the iron we may be able to explain some of these things. I merely offer this as a thought that apparently there is pretty good reason why these able engineers have gone on record that in certain classes of work they desire steel kept out of the mixture.

Another point I have in mind is that we have two or three irons here in this country, pig iron, rather, which carries relatively low percentages of vanadium and which contain nickel and chromium. Many metallurgical and foundry men have been at a serious loss to understand why remarkable properties have been attributed to the use of these mixtures in pig iron. The people handling these pig irons have not laid much less stress on the percentage of vanadium, nickel, chromium, etc., present in the pig iron, but have pointed out the fact that the metal was a well made pig iron product.

E. J. Lowry: During the past year I have been investigating the question of scrap in pig iron. The multitude of sins in scrap and the multitude in pig iron are not as they are being represented. I have taken photomicrographs of the entire surface of pig iron in which the uniform fracture which seems to be a cause of worry to some foundrymen is not so terrible as it looks, due to the fact that the close grain is caused by the formation of silicides separated from the iron. The separation of those silicides in this country, especially in machine casting, is due to the fact that the movement of the molten metal in the casting machine separates those silicides. There are two reasons for their formation, however. One is the fact of the movement of the casting machine; the other is the factor that the silicon which is expected in the pig iron as silicon may be there as unreduced silicates, meaning that they have a percentage of oxygen in combination with silicon. That is one of the causes for that dense area in the pig iron. Another cause may be attributed to the dissolved oxide in your iron and the factor of dissolved oxide is detectible when the polished area is etched under bromine fumes. In those instances the grain boundaries will have small pinhole slag inclusions.

I hardly believe that the author of this paper means all he says about scrap. I mean that only in this way, that American practice must be widely different from English practice. He states, on page 29, "The growing use of direct metal from the blast furnace to the steel furnace throws a larger scrap proportion upon the remaining furnaces using solid charges." Gentlemen, since the inception of hot metal in the steel

industry, the scrap percentage used has grown from 40 per cent to, in some instances, 100 per cent. I have just finished a run of three months making steel in which I have experimented with over 12,000 tons. We average 42 per cent hot metal one month and another month 38 per cent, and we worked as low as 32 per cent hot metal. The remainder was scrap.

If the steel furnace should reject scrap from its mixture and throw it on the market, this steel scrap usable in the steel industry is not usable in the foundry industry. Steel scrap entering the steel industry is of a quality which is much larger in size than the cupola could use. It has a specification which is "charging box size." That charging box size usually carries details of 6 feet by 14 inches by 24 inches. You can see that there would have to be larger cupolas to use it.

As to the use of scrap in the blast furnace, you will notice that the author has stated on page 29, "In the blast furnace not too rarely the charging of mixed cast iron and steel scrap iron and steel turnings, bundled detinned sheet and clipping scrap, to name a few of the odd materials, which generally unusuable elsewhere has resulted in a mixed variety of pig iron"—gentlemen, the detinned scrap bundle and all such scrap carrying a heavy weight per cubic foot of volume brings a premium in the open hearth furnace. Such scrap is not used in this country as blast furnace scrap. The type of scrap used in this country, and I have visited 105 furnaces out of 187, the usual type is bushelling, 8 inches and under in length, the other type is mixed borings and turnings, or borings or turnings.

While recently investigating blast furnaces, I found that, taking an iron made in a furnace without scrap and taking an iron after having used the scrap, such as borings and turnings, a superior iron resulted in that particular furnace. The reason for that superior iron was due to the fact that the reducibility of the ores was unfit for that particular blast furnace. In other words, a hard ore in combination with the borings and turnings entering that mixture permitted reducibility which was impossible before the introduction of the scrap. I found further that where blast furnaces have been using scrap of the type such as annealing boxes, 12 by 12 inches, that that type of scrap mightily influences the product and affects its value. I have further found that furnaces using pyrites affect the quality of the pig iron. There is no explainable reason for it, but put that pig iron in a malleable furnace, make malleable iron out of it and try to anneal it, and you will get frame structures throughout. Take that pig out and your malleable practice resumes its normal position, or you can use it by sweetening it by the use of another pig iron and get away with it, but you have to use it in smaller percentages. Dr. Moldenke said something about the magnetite ore of this country. The best pig iron made in this country is made from magnetite ore; it is the best

working ore you can use, provided your furnace is designed for that purpose.

In other words, condemnation has been placed on scrap in the blast furnace and probably rightly in some instances, because I have seen blast furnaces working on a bundle of sheets. The quality of pig iron is due to the reducibility of the ore and the combustibility of the coke. It is due to the same factors that influence the operation of your cupola. If you are going to make good iron, you must have certain factors and the same factors enter into the manufacture of pig iron. Dr. Moldenke will tell you that you can put in a certain mix, add some scrap and make the same casting as with a hundred per cent pig, and you can use bundle sheet, bushelings, put it in your ore and get superior pig iron.

I have now investigated 24 furnaces, having taken pig iron and put them under the microscope, put them in mixtures, run them 60 per cent pig and 40 per cent scrap, using one grade of pig iron, melting and casting it in various sections, and the predominating feature of the carbon structure in the pig iron persists into the casting. You can take two different pigs and two different carbon structures and you will get a mixture of carbon form throughout your cupola melting and into your casting. You can take cold blast—I have been investigating the only cold blast furnace today, the furnace Dover in Carlyle, Tenn.—you can take warm blast, semi-hot and hot blast, and as your temperature rises the qualities of the pig iron fall. This is another point verifying Mr. Fletcher's remarks. You can take those mixtures, cast them in the furnace, cut your test bars out of pig iron and you will get a definite strength, a consistent average. You can remelt them at the furnace as I have done, cast them into pigs, cut your test bar out and you markedly improve the strength. You are dealing with the same section. There is a purification action going on there and no oxidation taking place due to the fact that you are working with crucible covered charges. You can take the strongest iron you find, put it in the cupola and get porous iron in the casting. You can take a porous pig iron, put it in the cupola and get the best kind of a casting, depending on the way you treat the iron.

Referring to the status of scrap here, the author has mentioned cheap scrap. Cheap scrap is not prevalent in this country. Cheap scrap passed in this country in 1911, as the records will show. Cheap scrap is no more, due to the fact that the consumption is greater than the production, and the lack of scrap is purely imaginary. The accumulation of scrap depends on the freight rates of this country, which do not permit the scrap which is being made down in Texas and at foreign points to be brought into consuming areas like St. Louis, Chicago, Pittsburgh and Cleveland or any of the big consuming areas. Consequently you have an imaginary loss of scrap and your prices are high. Possibly the author did not mean scrap in the sense of cost, but in the sense of quality. The quality

depends on the specification. The specifications of the day are no more than subterfuges under which scrap is bought and sold; they are meaningless. Organizations like this carrying scrap specifications and writing them have written them without a purpose in mind other than to have something on which to go, and the quality of the scrap in the classes, even the most recent scrap specifications written by the purchasing agents in Milwaukee this year, means very little. Until some basic fundamental is put into those specifications, "cheap" scrap will persist. With the specifications being made properly, the problem does not become a metallurgical issue with the dealer in scrap; it becomes a requirement of the dealer to beat the specifications such as you fellows can use in the furnace.

Reducing the Cost of Cleaning Ferrous Castings*

By J. H. Hopp,** Chicago, Ill.

The first thought entering one's mind in connection with reducing cleaning costs centers about improved milling, blasting, chipping, grinding and handling equipment. The writer views the problem somewhat differently.

To reduce the cost of cleaning castings has, generally speaking, not received the study given other foundry operations. Manufacturers seek to produce a smooth appearing casting, requiring as little milling as will suffice to satisfy the user and at the same time one that requires a minimum amount of chipping and grinding.

Several operations have a very direct bearing on cleaning costs. It is the writer's contention that the first factor tending to reduce cleaning costs is not that of cleaning room equipment of methods, but comes directly under the general heading of equipment, molding, and core making.

It will be granted that the appearance of a casting can be controlled to a very large extent by the molder. The first requisite, however, is that of pattern equipment. Using patterns that are badly marred means either added molding time or a resulting casting—none too smooth in appearance, depending upon condition of patterns and core boxes.

Facing and Molding Sand Character

The grade, that is, a fineness or coarseness of the sand or the use of too coarse a mesh riddle, are items that cannot be neglected when appearance of the finished casting is an item of moment.

*This paper is presented on behalf of the Chicago Foundrymen's Club.
**President, The Hopp-Patterson Co.

Be the equipment ever so good and the molder use either a coarse riddle or coarse sand, one cannot hope for a very acceptable finish.

We cannot neglect the thickness of the casting and with this factor the strength of the facing that should or can be used. Attention, however, to this detail will not be productive of the best appearing casting possible, if the coarser grades of sea-coal are used and this may be further augmented, if the facing is not properly prepared.

A good facing sand should be prepared preferably 24 hours or longer in advance of its contemplated use to insure uniform temper. The sand and sea-coal must be mixed dry, in such proportion as the metal sections of the castings, to be made, seem to warrant. One should have a thoroughly mixed body of sand and sea-coal and by no stretch of the imagination should a facing be considered satisfactory that has been cut over only once or even twice, by hand.

The even distribution of the sea-coal throughout the body of sand can best be accomplished by the aid of mechanical equipment. It is the writer's opinion that a muller-type of mixer has proven itself as very well adapted to this task, as evidenced not only by its quite general use, but by the improved results obtained, These results are noticeable, especially in the appearance of the product, and the increase in bond due to mulling, thereby reducing the use of an excess proportion of new sand, and water necessary with, as a consequence, lesser rejections.

It is advisable to apply water to temper the mixture only after the sand and coal have been thoroughly mixed or mulled. Water in direct contact with the body of sea-coal, will cause lumps or balls, which will result in a mass that is not well blended.

Fins

Heavy fins on castings mean added chipping or possibly added grinding time, wheels and power. The molder cannot in all cases be held to task too severely in this connection. It is rightfully contended that to prevent a possible crush the mold must be

troweled down on the joint or parting and back a distance from the face of the mold. This operation results in a fin being formed along the joint line. Too frequently the molder over-does this and an unnecessarily heavy fin results, adding to the cost of cleaning. Reference is made to loose pattern molding as compared with plated work.

Effect of Gates and Risers

The molder can further increase the time required to clean the casting by his lack of care, or perhaps knowledge, in cutting gates and risers. Frequently, castings are lost from application of gates that are so heavy that when broken off they carry with them a portion of the actual casting itself. The writer has found invariably that a number of small gates is preferable to a single large gate not only with regard to reducing the cleaning time, but this method results in less defects due to better metal distribution and more uniform solidification of the metal.

The molder either through lack of care or knowledge, possibly to some extent custom or early training, feels that to make a casting without using at least one riser, and it seems generally speaking, the larger the better, would be suicide. He actually believes it is as necessary as the gate itself. Those of us who have had a diversified experience, particularly in production work, realize most readily the futility of trying to get the utmost value out of a riser.

My reason for belittling the use of the riser may best be understood when I say that it is the mis-use, rather than its use, that is being criticized. It is my personal opinion that more castings, steel and malleable excepted, are lost from the use of a riser or risers, than from failure to use risers. Even when sound reason and study has been expended with regard to number of risers and their location on a particular pattern, the casting may suffer and most frequently does suffer, because of the lack or kind of treatment given the riser after the mold has been poured. Too frequently this part of the task is considered lightly and entrusted to a laborer who has no knowledge of what he is trying to accomplish.

Risers only serve their purpose best when given attention, that is when properly churned or fed and only then, when located with respect to the varying metal sections of the casting and of a size and shape, which experience has taught is the best. Applying risers to castings and entrusting the feeding and churning to a laborer, is generally taking one more "long shot." Foundrymen, the world over, take too many chances and this may be one reason why so many are ready to take one more chance and trust themselves to fate.

Composition of Cores

We should not neglect to take into consideration another cause tending to increase the cost of cleaning, namely, the composition of the cores. Two cores may appear to be identical. Close inspection will reveal one core very much harder than the other. Though this core may not be so hard as to cause a "blow," it will be found that the harder core will require considerable more time to remove. Should the metal section of casting be rather heavy and the core not covered with a suitable wash, it will be found difficult to get the core to peel from the casting, thus adding to the cleaning time.

The various factors, previously brought to your attention, do contribute materially to cleaning costs, but are in no way controllable nor chargeable to the cleaning department. With the best of mechanical cleaning equipment costs could not be reduced to a reasonable amount, consistent with the grade of castings being made and the finish desired, if the foregoing factors are neglected.

Cleaning Department Factors

We will now consider the casting in the cleaning department, which is the starting point with so many who set out to investigate cleaning costs. Not only must one have good equipment, but on account of the conditions existing in the cleaning department, the equipment requires frequent inspection and checking up. When one stops to consider the dirty, sandy or grit-laden atmosphere in a cleaning room, it is nothing short of marvelous that the equipment remains in fair operating condition as long as it does. Could anything of a foreign nature be more detrimental to bearings than burned sand?

Mills

Considering tumbling barrels or mills, first, we should not fail to operate our mills at such increased speed over the manufacturers rating, as our castings will permit. It can be said generally that there are more mills operating too slow rather than too fast. Many mills are not sufficiently cleaned—either dust arresters are too small; fan operating too slow or not large enough; leaky pipes to dust arrester, or have other causes contributing in a like manner to increase cleaning time.

The operating man in charge starts off with new sharp iron stars, but lets them wear down until they are as small or smaller than marbles and as round. Buying soft stars—and there is a very great difference in degree of hardness in stars, is costly, to say the least, as they not only wear down too fast, but are slower in cleaning than harder stars. The practice of making one's own stars, it must be admitted, is not genuine economy, because the usual run of iron is far too soft.

Castings are generally cleaned by either tumbling in square or round mills, according to their shape, together with stars or by mineral or metallic blasting, using either a revolving barrel or table with fixed blast nozzles or blasting by operator in a special room. Sometimes both methods are necessary.

Sand Blasting vs. Milling

Each of these general methods has its good, as well as objectionable, features. Without enlarging upon that detail, suffice it to be said, that light, delicate castings readily broken or easily marred will be more acceptable when blasted. However, if a light casting is to be nickel-plated, blasting will cause trouble, as it has been found that a blasted casting oxidizes more readily than a milled casting. What might appear at a glance, as a job to be blasted, will often require special precautions to mill and more careful handling to reduce breakage. If the estimate covering cleaning has not taken these possible factors into consideration, the cleaning cost may exceed your estimate and still the cleaning department may be justified in its cost of cleaning these particular parts.

It might be well to add at this point that the foregoing statement must not be construed to mean that cleaning castings by milling is more costly than blasting castings. On the contrary, when all factors are taken into consideration, it is my opinion that under generally equal conditions, castings of a like nature can be cleaned by tumbling at from one-third to one-half *less* than the cost of blasting.

This general statement is based upon like depreciation of the equipment (20 per cent per year is estimated) and also on the basis of blasting equipment costing double what milling equipment costs. It is also estimated that labor will cost 25 to 50 per cent more if blasting method is used than when milling. It is conceded by those generally familiar with such costs that the cost of power in dollars per ton of castings cleaned, maintenance, material and labor are considerably lower for milling than for blasting.

One item of cost and a very important one is compressed air. Its cost is rarely estimated high enough. Air loss in lines due to screwed joints not being made up tight—valves that leak—holes in hose, etc., means added cost. A ⅛-inch diameter hole or its equivalent, will at 80 pounds pressure permit the escape of 21.2 cubic feet of air per minute.

Castings that can be milled or blasted will cost less to grind when milled than when blasted, as milling helps to remove the fins. The appearance, however, of two like castings, cleaned by these alternate processes, is entirely different—that is—in surface appearance. It would be simply out of the question to mill certain castings and retain the original intent of the pattern.

Large castings—too large to tumble conveniently, are sometimes rough brushed and ground with swing frame grinders. It must be admitted, however, that the appearance of such castings is enhanced by blasting. The writer has seen large castings cleaned by the use of water in place of mineral or metallic abrasive. The water was delivered to the hose nozzle at high pressure by means of tri-plex pump and the results were very acceptable. Rust will set up very quickly, but as such castings are generally filled and painted, the rust is not of serious consequence.

Determining Cleaning Method

The nature of the casting, its size, shape, design and ultimate use determines to a very large extent how it shall be cleaned, so no definite rule can be laid down. However, as we are concerned in the matter of reducing costs, one must determine from the factors mentioned that method or combination of methods which will make for low cleaning cost, and still give desired finish.

For example, consider a water jacketed cylinder casting. To mill this might appear the cheaper way. Close study will reveal the necessity of cleaning the jackets in and around the ports and valves. To do this by milling alone would, in my opinion, require more time and be a less certain method than by blasting in the many corners and cored spaces. So all in all, it probably would be best to blast the entire casting rather than put it through both processes.

Some go so far as to claim that milling a casting increases its strength. The writer feels this is a very fine point and wishes to leave no such inference. On the other hand, the foregoing remarks should not be construed to mean anything more or less than this, that each method has a place in the industry. Some classes of work can perhaps be cleaned by either method, in other words, the question of best method is debatable. On the other hand, some classes of castings demand the one method in preference to the other. This is true with regard to the majority of castings to be cleaned and it is contended that where it is possible to clean by milling and when that sort of finish is acceptable and cost is a factor, one should be able to clean them satisfactorily at a lower cost than would be possible, if blasted.

Having in mind certain cases where it is possible both from the nature of the casting and the quantity required to adopt some form of continuous cleaning arrangement, even though castings be well suited ordinarily to milling, it will be found advantageous to use blast method of cleaning. As all problems are not production jobs in the strict sense of the word, one must guard against installing expensive equipment, and increasing the investment cost.

Mills are usually placed on the floor of the cleaning room and loaded and unloaded from and to trucks or tote boxes, placed on the same floor level. A rather inexpensive way to load certain classes of castings into mills can be accomplished by building a platform above the floor level, at a suitable height and in the rear of the mills, with ramp or runway of easy rise leading to raised floor level. This method only lends itself to castings that can be dumped into mills and do not require being packed. After milling they can then be dumped into receptacles on the main floor. This will reduce the handling charge or amount of labor required. It is obvious that castings requiring packing in mills will cost more to clean and cannot so be handled.

Estimating Costs

Bidding a lump price per pound on castings to be made, whether small or large, cored or otherwise, including everything and anything, is a rather sure way of adding to one's losses, for invariably some other foundrymen will come along and quote a lower price on the heavier castings and these patterns will soon find their way to another shop, and the foundrymen who took the order originally on an average price is left with the lighter and less desirable work. This same reasoning applies to cost of cleaning castings. One should estimate cleaning cost as well as other costs, if he seriously intends remaining in the foundry business.

Grinding

While it is quite impossible to discuss in detail each and every operation in so brief a space of time as allotted, the writer feels that the subject assigned to him would not be complete, even though brief, unless some facts were brought out regarding grinding.

The rapid removal of metal by grinding wheel is generally understood. There would be little debate following the general statement that operating a given wheel faster than usual practise would, in most cases, result in cutting away the metal to be removed in less time. Before doing this we must consider whether the make-up of the wheel will permit higher speed with safety to the workman, and at the same time not become fouled.

Analyzing the reason for the decreased grinding time it will be plainly seen that this is due to bringing a larger number of particles of the abrasive in contact with the metal to be removed. If it were possible to have a wheel containing all abrasive material and no bonding ingredients, one could reduce the grinding time considerably. However, it is obvious, such a wheel would not be practical.

The practical solution of the problem is first a bonding material of greater strength than has been generally used in the past. This will serve a dual purpose, permitting first, of the introduction of a greater quantity of abrasive material in proportion to amount of bonding ingredient, and secondly, greater strength of bonding material will permit higher speed, i.e., circumference speed, in feet per minute.

Rubber Bonded Grinding Wheels

In the recent automobile race at Indianapolis, taking the winner's average at 100 miles per hour, slightly less than he actually accomplished, consider that in one hour's time, neglecting slippage, the circumference of the tires traveled more than one-half million feet, say 528,000 feet or at the rate of 8800 feet per minute. It has been stated that at a circumference speed of 5 miles per minute, rubber tires show no signs of tearing themselves apart.

In view of these experiences and the fact that rubber will bear more change in dimension and still return to its original shape and size, than any other commercial material, it is not, then to be wondered at, that experiments have been conducted along the lines of using rubber as a bonding material in place of the materials so generally used in making vitrified wheels.

However, one can not hope to affect any real economies even with the use of wheels having an increased volume of cutting grits exposed in the face of the wheels to the work, unless the grinding equipment be heavy enough to withstand the higher speeds and not vibrate. This means larger spindle diameters and heavy ball bearings. It must be obvious that rubber bonded wheels can be and are made in a variety of grades. For fast

cutting, high production, the use of "soft" wheels are necessary, but rigidity of equipment throughout is absolutely essential.

Rubber bonded wheels, made of imported abrasive material, operating at 8000 surface feet per minute, are in daily use giving excellent results. Though these wheels sell at higher prices than vitrified wheels, one must not consider the grinding cost as being simply based on wheel cost. The actual number of pounds of metal removed with a record of the time in which this is accomplished and a record of the incident loss in weight of wheel used are the important controlling factors governing cost.

However, rubber bonded wheels are at present adapted to cutting steel, hard iron (malleable) and alloys steel. In some cases, they have been used successfully with other metals, even non-ferrous metals, but their development has not proceeded to a point that recommends them for cast iron grinding, bearing in mind that we are after faster metal removal.

On the other hand, consider monel and ni-chrome, these metals are what one might term soft and pasty. The pores of vitrified wheels become clogged, the wheel face fills, and frequent dressing is necessary, and incidently, high wheel wastage results.

The denseness or compactness of rubber bonded wheels means that there are less pores, practically none to fill up, with less dressing and less wastage. This incidently changes the order of things in grinding malleables. Vitrified wheels are best suited to grinding unannealed malleables, whereas the rubber bonded wheels can be used on the annealed malleables.

In concluding, it can only be said that the foregoing covers suggestions, which if studied and applied, will result in reducing the time required to clean the castings. Equipment, molding and core making while requiring added time possibly, will in the end, help reduce cleaning costs.

DISCUSSION

R. S. MacPherran: It would seem to me the author has not given enough prominence to the cleaning of large castings by water. The introduction of this method of which he speaks of is becoming more and more common and we find a wonderful saving in the actual cleaning time. A

friend of ours, to cite one case, put in equipment and on one casting of theirs, the cleaning time was dropped from 130 odd hours to 8 hours. Of course, you add to this time, the time taken for chipping off the fins. As for getting the cores out there is no comparison at all of the old system to the water system.

DR. R. MOLDENKE: I would like to see the cleaning done away with altogether, if possible. Why not try to make our molds such that we do not have to clean the castings. If we could work in the direction of preparing our mold so that we would have a minimum of cleaning afterwards, we would work in a much better direction than reducing the time of cleaning. We have not yet got facings, and finishings to a point where they ought to be brought in order to get the best results.

H. J. MOORE: I would like to ask Mr. MacPherran what pressure is used by the Allis-Chalmers Company?

R. S. MACPHERRAN: The water pressure is about 300 pounds. There are two streams above and two more below. The large castings are cleaned separately. The smaller ones, 2,000 pounds or so in weight, are put in large crates and set on the tables. The operators turn these tables around so they can shoot right into the cores. It is only from cleaning out the cores that this paper spoke of "rusting." This rusting is no more severe, however, than if you put the castings out in the yard for a week and get them rained on; it simply gets the castings wet, it has no other effect on them at all.

MR. TOLMLEY: I would like to ask in what manner they disposed of the material washed out, the core sand?

R. S. MACPHERRAN: It drops down into a big tank. We thought at first that it would abrade our pumps, but it has not affected the pumps seriously at all. It settles in the bottom of the tank, and about every so often we open the tank and take the material out with the clam shell grab. When the water becomes bad we throw it away.

MR. TOLMLEY: A plant in Hamilton used that method of cleaning engine beds and they clogged the sewers up and the city got out an injunction against them.

R. S. MACPHERRAN: The waste does not go into our sewers. We clean the tank every three to five months but we use most of the escaped matter over again.

J. M. SAMPSON: At the G. E. Co. Erie works they have a hydraulic cleaning device, and the management at Schenectady wondered why we do not use it. I wonder what figures Mr. MacPherran uses as to the work, the foundry floor space occupied while the castings are cooling off preparatory to putting them in the hydraulic room? We figure that our floor space is worth possibly a dollar a square foot per year, and our large work requires 6,000 to 7,000 square feet while the castings are cooling off. Even though the over-all time may not be very great, it does not have

to be very great if the shop is pretty well crowded, to decrease your molding space and your output and service to your customer. In a great many communities such as Schenectady, where we hit water in the neighborhood of five feet from the floor level, the settling takes considerable time and costs a lot of money. I would like to know whether or not the Allis-Chalmers Co. has made any real study showing what those costs would be, and if they have, I would like to have the result.

R. S. MacPherran: We have made no real study of that condition. The castings have to be on the floor a little longer than ordinary, but when you can save materially on the cleaning time you can deliver the castings almost at the same time you otherwise could.

J. M. Sampson: The over-all time is no greater?

R. S. MacPherran: Not to amount to anything, as too sudden cooling may cause strains. You should leave the castings until cold enough to put your hand on them.

G. K. Elliott: Once in a while we run across a man with a real lively imagination. I ran into one of them the other day and he held out an idea which rather shocked me. It fits in here somewhat. His idea was, 'why not make molds out of lime?' He did not say how you were going to do it; he just said, 'Why not make molds out of lime and dissolve the mold, core and all with a hose and not have any sand to dispose of afterwards at all?' I leave the suggestion with you.

Jas. Prendergast: I would like to ask how in cleaning castings by water they handle this proposition in a cold northern climate during the winter?

R. S. MacPherran: Our installation is inside the foundry. The whole thing is enclosed, it does not work outdoors at all.

Foundry Progress: Past, Present and Future

By J. D. Towne,* Dayton, Ohio

Foundries, and the industry of casting metals, have been in existence practically as long as the human race and, while it has been only within the last two hundred years that the industry, especially iron, steel and aluminum, has assumed proportions of major importance, we find mention of brass founding in the early chapters of the Bible, and intricate specimens of the art, in brass, have been recently uncovered in China that date back to a period long before the time of Christ.

Physically the human race has changed but little since its creation, and in many ways it seems the foundry industry has been just as constant in remaining true to its original methods. Practices have changed to suit conditions of civilization but in considering the basic elements underlying the industry, it would seem that many are the same today, and have remained the same constantly throughout the ages.

Early Developments

War had a great part in causing man to first appreciate the value of cast iron. Late in the Fourteenth Century it was discovered that the molten metal which occasionally ran from the furnaces used in the production of wrought iron, had a high manganese content and was very suitable to cast into cannon balls. Up to this time, the furnace operators had been heavily penalized for permitting their metal to become molten, and consequently wasted. Cast iron quickly assumed equal importance with wrought iron and the furnaces were operated alternately from one metal to the other as more experience and knowledge were gained, and it was soon learned that the new metal was practical for cannons and for stove plates. Shortly after this, cast iron appeared prominently in both Germany and England and "Pig

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Iron" was cast in the latter country in open molds in forms almost identical with those used today.

One of the first commercial iron foundries of which we have any record was organized in 1707, at Colebrookdale, England, by Abraham Darby. This foundry passed on from father to son through the generations and even today enjoys an enviable reputation for its product of both cast iron and bronze. When the original Mr. Darby first started his foundry the problem that confronted him, and upon which hinged success or failure, was an effectual method of leading away the gases that formed in the cores. This problem was successfully solved by a young Welsh lad, who vented the cores in the same manner we vent today, and so made possible the continued success of cored casting.

As an example of early foundry sales and buying practice, which we must admit has undergone considerable change up to the present date, the following quotation from the writings of Reaumur, the eminent French metallurgist of the early Eighteenth Century will be found interesting: "There are founders who do nothing every day but to melt cast iron and no other metal. Their number is not large, and I do not know whether there are more than one or two in Paris. These founders travel through the country, and make their appearance gradually in different provinces. They make cast iron weights, plates for different purposes, cast new and patch old hollow ware. The founders buy the pig iron they want from peddlers, who gather cast iron scrap in the villages in the vicinity of Paris. This scrap is exchanged for apples; a man with scales in one hand, leading a horse laden with poor fruit, does the business, exchanging apples for iron, weight for weight."

Foundrymen Slow to Change Methods

During these last two hundred years the class and design of castings has changed greatly to meet the increasing improvements in all the other lines of industrial endeavor, but the foundry methods of today are practically the same as they were in those days of long ago. The foundry has not seemingly attempted to keep step with the strides made by those other industries which

the foundry serves and even at this time when the others are making wonderful strides in conserving men and material through the use of advanced methods of management, the foundry lags behind and not only declines to take the lead, but even hesitates to take advantage of the experience worked out and developed in other trades.

There have been in the foundry industry, as in every other line, successful managers who had no so-called "system" of handling their business, but nevertheless these same successful managers, whether intentionally or unintentionally, were all, it is safe to assert, using the same general principles of management, and these same general principles are now and must always remain the foundation of real success. If foundries, as an industry, will accept the lead of a few groups and individuals from their midst and seriously take up the subject of improving their management methods, a real step of progress will have been made and the industry will be moving forward from the darkness of the past ages into the light of progressiveness and advancement.

General Principles of Management Applicable to Foundry

Considered as a whole, the foundry presents no greater difficulties for the application of improved methods of management than any other industry; but rather it may be safely said, the foundry lends itself more readily to improvement than many other manufacturing plants and holds far fewer snares and pitfalls than most foundrymen imagine. It seems to be unfailingly the custom for each tradesman to agree that certain, or all, improvements are splendid and proper for some other industry, but cannot possibly be used in his own trade on account of certain peculiarities of which he is always ready to speak. This has been the determined attitude of most foundrymen and they have consequently succeeded in holding back the progress of their industry. There are, however, sufficient, although comparatively few foundries that have taken the advanced steps to demonstrate the permanent improvements that can be secured, which include decreased costs, increased production, improved quality and deliveries, and increased earnings for the workers and stock holders.

Misunderstanding of Principles of Management

There is a very general misunderstanding of the meaning and extent of modern methods of management. In spite of the mass of literature that has been published covering all its various phases, the idea is quite prevalent that practically the entire plan is covered by an incentive wage system, whether it be bonus, piece work, or some other method of payment for the workers, and if a stop watch has been even crudely used in setting the rates, in many minds the last possible step has been taken. The system of wage payment is indeed a very small element when the entire broad program of management is considered and should be one of the last factors taken up. While time study is a very important part of the entire plan, there have been so many unfortunate cases where the time study observer has been a failure through lack of experience or training, it is doubly essential to be sure the man using the stop watch is competent to do so.

For the benefit of those interested in knowing just what is covered by modern methods of management, I wish there was an adequate definition to be given that would place the entire question clearly in all our minds; but the field is so broad, the question so big, that it is impossible to define it. Definition necessarily means limitation, whereas these methods are constantly growing and expanding year by year, taking advantage of every possible improvement and no limits can be placed upon them at this time. Some idea of the scope of the question may be gained in realizing that management covers proper selling, planning, manufacturing and accounting, although planning and manufacturing are the two headings under which most progress is being made today, and the former is the real phase that makes almost any management methods worth while, and without which no intelligent progress can be made.

Until comparatively recent years the tradesman or mechanic was the source of all progress in industry and the knowledge of today was passed on to the apprentice, to be used tomorrow and again passed on. This entire plan has changed with the advent of the shop engineer. We find him making scientific investigations, working out solutions to the problems that have

been perplexing in the past, and readily accepting the responsibility of training workers in habits of industry after the best method of performance has been determined. And it is not the workman alone that must be trained into the proper way of performing his job, for it is even more essential to be sure the foreman in each department thoroughly understands his duties and what is expected of him, and that he is in thorough sympathy with the progressive policies of the company.

Various foremen take the advent of a shop engineer in very different ways! Some few welcome his coming and openly admit they are anxious to be relieved of certain detailed responsibilities in order to spend more time on various duties demanding their attention; many other foremen are lukewarm, doubtful in their own minds as to the wisdom of the step the management is taking, but willing to be shown, although far from enthusiastic in their cooperation; and there are other foremen who are openly antagonistic and refuse, as far as possible, to do anything to assist in the work, although most of their opposition is done in an underhand and quiet way. The foreman is the connecting link between the worker and the management, the foreman represents, to his men, the entire company and whatever his attitude may be on any question the worker very quickly knows it and that attitude is immediately taken as the company policy. For this reason the foreman must be carefully trained, shown the wisdom of each move to be taken, and so handled that he will unknowingly perhaps, fall in line and pass on to the workers the proper spirit and understanding.

Planning Department Important

One of the biggest changes made under the new methods is the planning of all work by a planning department instead of leaving it to the judgment of a busy foreman, in which case there is probably no planning done at all. In most instances where this is true the work costs in wages two to three times what it otherwise would, but the fault cannot actually be charged to the foreman. It has been frequently demonstrated that practically any job in the foundry can be studied and planned, and if the results and recommendations are carried out almost unbelievable

waste is eliminated, and at the same time the workers are given an opportunity to earn more pay through increased production, with greater satisfaction resulting in every way.

It has been admitted by manufacturers' associations that the majority of strikes are the results of mismanagement, for it is very evident that satisfied and well paid men are rarely interested in agitations and talks of strikes. In several instances within recent years the labor unions have demanded, when making strike settlements, that the company take up modern methods of management instead of the old worn out system that previously prevailed and under which neither workers nor owners could prosper. The unions have realized more and more of late that the methods they at first decried and fought at every opportunity, in reality hold the key to the entire situation and, if used properly, will mean the end of the century-old combat between capital and labor. It should be borne in mind that all misguided effort is an absolute loss and must ultimately be paid for by either the workers or the employers; consequently if the elimination of waste of this sort was the only benefit to be derived, it would seem that the financial return would be well worth while for all concerned.

An Example of Old Conditions in Cleaning Department

To give an actual example of what can be done in the foundry, let us consider a case that may be looked upon in every sense as typical, a cleaning room in a large steel foundry in the middle West. The department employed, as usual, in cleaning rooms, unskilled labor which included Negroes, Hungarians and Italians, in the majority, with a few Americans scattered through. The castings were shaken out in the foundry and delivered usually red hot to the flogging floor, with great heads and gates attached, and placed in a large pile by an overhead traveling crane until frequently there would be an accumulation of several hundred castings averaging over two hundred pounds each, the pile reaching thirty feet or more high. This meant not only losses and serious delays in shipping of castings that unfortunately landed at the bottom of the pile, meaning trouble for the sales department in their connection with the customers, but it also caused an extremely dangerous hazard for the workers, who were forced

to use long bars in pulling loose the individual castings from the large pile, all the while keeping an active eye trained upon the castings higher up and quickly jumping clear when one would begin to slip.

Troubles Encountered Under Old Methods

After the castings had been laboriously drawn from this death trap and flogged, they were sand blasted in the old style room, that has caused more than one good man to give up with consumption. Following in the proper order came the chipping, welding, swing grinding, tumbling barrels, aerial grinding and inspecting. At practically every point difficulty was being experienced in holding the men to their jobs and preventing them from laying off from one to three days each week. This uncertainty as to how many men would be on hand each day caused extra men to be hired for each operation, as a safety factor, and what these "extras" lacked in skill the foreman made up in quantity. Due to no definite policy as to what constituted a fair day's work nothing moved very fast, the several operations were not balanced for equal production and the entire situation resulted in deplorable jams forming that necessitated the foundry shutting down for a day or two each week to enable the cleaning room, by working all day Saturday and Sunday, to be fairly well caught up to start off fresh Monday morning.

A large machine shop, belonging to the same company that machined practically all the castings made, was continuously held up by the cleaning room condition and was unable to meet its requirements through lack of material. Making conditions even worse, many of the castings were found full of mis-runs, blow holes, were porous, and had shrinks, cracks, etc., that necessitated welding in the cleaning room and reoperating much of the preceding work. It was very evident that this department was the weakest spot of the entire organization, veritably the neck of the bottle, and it was decided it was here that immediate improvement must be made.

The foreman was a hard worker who had been with the company since early in its organization and was given a free hand in the operating of his department. Although sincere in his belief

that he was running the cleaning room in the best possible way, he was deplorably weak in management—handling men and materials—as can be appreciated when it is stated that by far most of his time was spent in moving the castings, with his own hands, from one operation point to the next, and paying no real attention to the quantity or quality of work each or any of his men was turning out. The two chief operations in the department, chipping and aerial grinding, had been put on piece work by the "guess" system of setting rates, with the results that the prices had been cut several times and that the men were still making from $1.00 to $1.20 per hour when the prevailing rate for similar work in the same district was from 50 to 60 cents per hour. On several occasions in the past these workers had threatened to quit for various reasons of minor importance, but the foreman always claimed it would be impossible to replace them, they having been with the company so long, and that the logical thing was to permit them to earn sufficient money so as to be sure they would be satisfied. Not all the chippers and grinders had piece work, only four of the best men on each operation being paid in this way, and these were supplemented by as many more men as seemed necessary, who were paid a straight hourly rate and given all the difficult jobs that the piece workers did not care for and no attention was paid to their production. The men, working on the several other operations in the department were also paid straight hourly rates and no records kept of any of the work done.

Analytical Study Made

A thorough study was made of the department covering (a) the equipment and layout, (b) the workers, both direct and indirect, and (c) the method of performing the different operations. It was decided immediately that the dangerous pile of castings must be eliminated entirely, and the unhealthful sand blast room was condemned to be supplanted by the modern type of revolving table that permits the sand blast operator to work in the open away from most of the disagreeable dust and sand. In making the changes, an entire new order of work plan was developed, bringing the castings to the cleaning room in an orderly manner on trolley conveyors, permitting the work to progress through

the department in the proper sequence, eliminating practically all of the back tracking and handling that had been so prevalent before. A new section was acquired for the tumbling barrel room, relieving the congestion in the entire department and giving ample room for each operation to be performed properly. By calling attention to the many defective castings received from the foundry, a campaign was started in that department to eliminate all possible defects in metal and molding with the result that the necessary welding was greatly reduced and the machine shop was quick to notice that the castings were more readily machined, resulting in a greater production and reduced tool and labor costs.

The men in the cleaning room were all "old timers," men who had grown accustomed to the unsystematic and careless ways the department was operated and who had been pampered and permitted to have things their own way for so long that they had fallen into a veritable habit that was reflected in every particular by their environment. It cannot be too greatly emphasized that one of the most important points in securing increased efficiency in any department or plan is to develop in the workers habits of industry, as well as knowledge and skill.

Every operation in the cleaning room was studied thoroughly. Time studies were made of every detail, carefully checked, analyzed and tabulated, and developed according to the routing plan for the work. When the department had been completely covered and the new program entirely worked out, the plant superintendent and department foreman were called into consultation before any attempt was made to put the plans into effect.

The customary arguments against such seemingly radical moves were advanced in full strength. These included (a) "the tasks set were entirely too high and impossible to make;" (b) "the work could not be handled in the manner specified, as it had always been done the other way and the new plan would only cause confusion and jams;" (c) "the men would no doubt be dissatisfied and quit at once, making it impossible to get out the work;" (d) "if the workers did attempt to increase their production the quality would suffer to such an extent that the company would lose heavily;" (e) "if the force was reduced so greatly

every time a man was off it would mean hiring some one to take his place." Many other objections were advanced and argued, but fortunately the management was squarely behind the program and the changes were made, despite the fact that it was very evident the objections were still far from forgotten.

Changes Made

The reductions in the working force were made according to the schedule which was worked out from the job analysis and time studies. This schedule is shown in Table 1.

Table 1

SCHEDULE OF MEN IN CLEANING DEPARTMENT SECTIONS UNDER OLD AND NEW PLANS

Operation	Number of Men at Present	Number of Men Required
Flogging	4	2
1st Sand Blast	2	2
Cut Off	2	1
Chipping	11	8
Inspection	2	2
Welding	2	1
Swing Grinding	4	2
2nd Sand Blast	4	2
Tumbling Barrels	6	4
Aerial Grinding	14	7
Miscellaneous Labor	5	4
	56	35

The changes were not all made in one day, but spread over a period of about three weeks, one or two operations taken at a time and developed according to the new methods and then, when these were working smoothly, one or two more added to the list. All the operations were changed from day work and piece work to bonus, based on standards set from time studies. As can be judged from the above schedule, in most cases the new standards called for about one hundred per cent greater production than the previous average had been. In the cases of the piece workers, besides calling for increased production, it was also necessary to reduce the earnings to a rate only reasonably higher than the average for that class of work in the district; in other words, the production was increased and the wages reduced, but despite this fact not a single man quit. Aside from the inefficient workers who were laid off, it was necessary to discharge only one

man for "stalling" and talking too much; this man had caused trouble in the past and it was thought best to rid the department of him while the general cleanup was in progress. The man was one of the few white Americans employed in the department.

Answers to Objections

In regard to the various objections offered at the start: (a) After the various workers had been instructed in what was expected of them and thoroughly understood the new methods, they set to their work in earnest and the new bonus rates were readily and consistently attained; (b) the work moved far more smoothly through the department without jams at any of the operations, consequently eliminating practically all confusion; (c) while the few men whose earnings had been reduced were naturally not pleased, all the others were delighted with the opportunity to make more money, even though they had to increase their production, and all, without exception, were more than favorably impressed with the guarantee given with all rates that, no matter how long the jobs ran with the same equipment and methods, the rates would never be cut; (d) while increasing production the quality was readily held up to standard, and improved over previous custom, by permitting the inspectors to earn bonus based upon both the quantity of work handled and the standard of quality to which they held the work they inspected; (e) by paying the workers a wage somewhat higher than the average in the other shops in the district, each worker was interested in holding his job against some outsider; and, besides this, the former piece workers, who had previously made such exorbitant wages and consequently could afford to lay off a day or two each week, now earned only a reasonable rate and knew, in order to receive at the end of the week a check sufficiently large to meet their requirements, they should work every day.

The example cited is by no means extreme. Many other actual cases in any department of the foundry could be given that would parallel this one. It is these leaks, representing hundreds of thousands of dollars each year in many large foundries, and relatively less amounts as the plants considered grow smaller, that

could be readily stopped if the managements were awake, not only to the possibility of stopping them, but by far more important, if they could realize that many, and I'll venture to say, most, of the departments in their foundries could be reorganized and developed to show unbelievable savings.

In a volume published thirty-two years ago by Simpson Bolland, after mentioning the progress made in the preceding thirty years (taking us now back over sixty years) and listing under this general heading practically all of our present day equipment, he writes, "When so much has been accomplished by the uneducated founder in the past what are we entitled to expect in the future from this added intelligence? Time will show. The age is pregnant with ideas. The full blaze of scientific knowledge is lighting up dark and hitherto mysterious nooks in which nature has hidden many precious secrets. *To suppose the useful and noble art of iron founding will not share in the riches thus lavishly obtained would be to rank it as among the least progressive of the mechanic arts; whereas recent advances show it is no longer wedded to ancient ideas and methods, but is eager to embrace any and all sound improvement.*"

Mr. Bolland unknowingly penned a present day indictment of iron founding (and of all foundries) which it is difficult to answer; but if we will use his words as though they were written today, instead of a third of a century ago, we can look to the future with a new determination; realize our weak spots; concentrate our efforts upon correcting them; and, by bringing our methods to the standards upheld by other industries, remove from foundries in general the stigma of unprogressiveness now so readily and deservedly placed upon them. Let us lead in progress in the future!

The Qualities of Commercial Core Oils

By H. L. Campbell,* Ann Arbor, Michigan

Mixtures of drying oils are used extensively as the bonding material in dry-sand cores. Linseed oil, soya bean oil, tung oil and other oils which become sticky and finally hard when they are oxidized are known as drying oils. In general the practice for preparing commercial core oils, consists in dissolving rosin in drying oils, with the aid of heat, and thinning the mixture with mineral oil. Both the rosin and drying oil have bonding properties, while the mineral oil assists in distributing the bonding material throughout the sand.

The ratio of core oil to sand is fixed so as to produce the required properties in the finished cores. This proportion varies over a wide range in different foundries, depending upon the quality of the core oil, the grade of sand used, the admixture of other binders, and the method used in making the cores. Some water is generally added when preparing mixtures of core oil and sand. During the baking period, moisture is evaporated, the mineral oil is volatilized and the drying oil is hardened by uniting with oxygen of the air.

There are advantages in the use of core oil which are not obtained with other kinds of binders. In addition to having high bonding strength, oil-sand cores have sufficient porosity to allow the gases generated within the cores to escape freely. Small cores of intricate design can be used successfully when bonded with drying oils. Oil-sand cores do not absorb moisture and may be stored for long periods before being used. At high temperatures the bond is destroyed and this allows the core sand to be removed easily from the castings, when oil-sand cores are used.

With the purpose of establishing some method for determining the relative qualities or values of oil binders for cores, a study

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has been made of the properties of twenty-three commercial core oils. Representative samples of these oils were collected from many sources and were transferred to large, glass bottles which were marked with letters only. In this investigation, the chemical and physical properties of the core oils were obtained as well as the physical properties of cores made with the oils, in order to note any relationship in these characteristics.

Chemical and Physical Properties of Core Oils

In standard specifications for pure oils such as linseed oil, soya bean oil, and tung oil, limitations are given for specific gravity, refractive index, iodine number, and unsaponifiable matter. Each of these properties indicates in some degree the purity of the oil. The values of these properties were found for each of the twenty-three commercial core oils. These data are given in Table 1.

Table I

PROPERTIES OF COMMERCIAL CORE OILS

Oil	Specific Gravity	Refractive Index	Iodine Number	Unsaponifiable Matter Pct. by weight	Maximum Transverse Strength, Pounds	Average Transverse Strength, over 75°F.
A	.939	1.4938	142.5	12.08	29	25
B	.949	1.4928	155.5	16.39	44	36
C	.901	1.4772	130.2	12.0	31	29
D	.894	1.4777	126.3	17.14	26	25
E	.888	1.4753	123.5	70.33	22	21
F	.926	1.4875	147.0	40.91	33	31
G	.944	1.4865	153.2	18.0	34	33
H	.934	1.4995	91.4	5.2	33	29
I	.944	1.4960	155.2	8.3	47	42
J	.956	1.4920	180.3	16.65	43	38
K	.943	1.4930	157.0	19.17	30	24
L	.942	1.4910	172.5	1.01	29	25
M	.941	1.4853	103.7	1.00	33	29
N	.930	1.4843	147.6	1.43	34	30
O	.939	1.4933	151.0	71.5	34	23
P	.942	1.4910	102.0	35.7	32	29
Q	.924	1.4901	135.0	46.8	34	31
R	.935	1.4903	157.0	54.3	38	34
S	.956	1.4950	132.6	18.5	33	32
T	.924	1.4880	131.2	23.5	21	18
U	?	?	?	?	27	24
V	.946	1.4779	121.8	4.5	40	32
W	.922	1.4730	123.2	5.2	33	31
Linseed	.936 to .931	1.4805 to 1.4780	170	1.50	54	51

The specific gravity of a core oil is the ratio of the weight of a unit volume of the oil to the weight of an equal volume of water. As the specific gravity of a mixed core oil is the resultant of the specific gravities of its components, this property offers little assistance in establishing the exact quality of an unknown oil. An oil with a low specific gravity would probably contain a large proportion of mineral oil thinner.

The refractive index is a physical property which is constant for a pure oil. This test is based upon the observation that when a ray of light passes from one medium to another it bends and the angle of deflection can be measured.

The iodine number is a measure of the amount of materials in an oil which react with iodine. This is an indication of the amount of oxygen which can be taken up by the oil to form a bond in the core. Mineral oils have low iodine numbers and produce little bonding strength. The dilution of a pure drying oil with petroleum may be detected by a low iodine number. As the iodine numbers of different drying oils vary considerably, this property is not a definite indication of the dilution of a drying oil mixture.

The proportion of mineral oil which has been added to a pure drying oil can be determined by an analysis for unsaponifiable matter. The higher the unsaponifiable matter in an oil mixture, the greater is the mineral oil content.

Physical Properties of Cores

In this investigation of core-oil binders, it was necessary to develop methods and equipment for determining the physical properties of cores. After some preliminary experiments, it was decided that the transverse test gave the most satisfactory results in arriving at the bonding strength of cores. This method of testing approaches closely the conditions under which cores are used in the foundry. Cores of standard size, 1 by 1 by 8 inches, were tested transversely with a distance of 6 inches between the lower supports on the testing machine.

One factor which influences the results of physical tests of cores is the practice used in making the cores. It was recognized

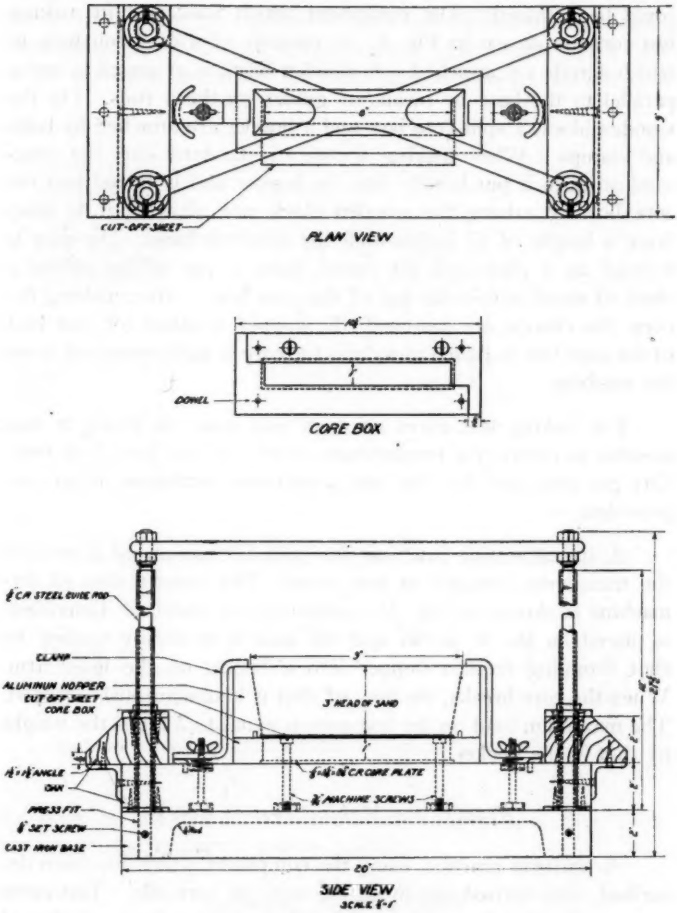

FIG. 1—EQUIPMENT USED IN MAKING CORES

at the beginning of this investigation that a uniform method for making test cores was necessary before any comparative data could be obtained. The equipment which was used in making test cores is shown in Fig. 1. It consists of a cast-iron base to which 4 rods are attached. A wooden block is arranged to move parallel to the base by means of guides on the 4 rods. On the wooden block, a split core box and a hopper are attached by bolts and clamps. When making a core of standard size, the core-sand mixture is put loosely into the hopper and is jarred into the core box by raising the wooden block and allowing it to drop from a height of 12 inches onto the cast-iron base. The core is formed on a plate and the excess sand is cut off by sliding a sheet of metal across the top of the core box. After making the core, the clamps are loosened, the hopper is taken off, one-half of the core box is pulled away and the core is easily removed from the machine.

For baking test cores an oven was used, in which it was possible to control the temperature closely for any period of time. City gas was used for fuel and a uniform circulation of air was provided.

A special testing machine was built for measuring accurately the transverse strength of test cores. The construction of this machine is shown in Fig. 2. A test core of standard dimensions is placed on the V blocks and the load is gradually applied by shot dropping from a hopper into a bucket on the lever arm. When the core breaks, the flow of shot is instantaneously stopped. The maximum load on the test core is equal to 3 times the weight of shot in the bucket.

Practice for Making Test of Cores

A uniform practice, using the equipment which has been described, was carried out in all the tests on core oils. Test cores were made of mixtures containing 1 part by volume of oil and 50 parts by volume of dry sand. A clean, Michigan City core sand which passed a 40 mesh sieve was used in all of the core mixtures. Distilled water in the proportion of 8 per cent of the volume of sand was added to each batch which was mixed for 5

minutes in a small, paddle mixer. When making the test cores, the practice was to jar the oil-sand mixture into the core box 15 times. The cores were placed in the oven which had been heated throughout at the desired temperature. After baking for 1 hour at the correct temperature, the cores were removed from the oven.

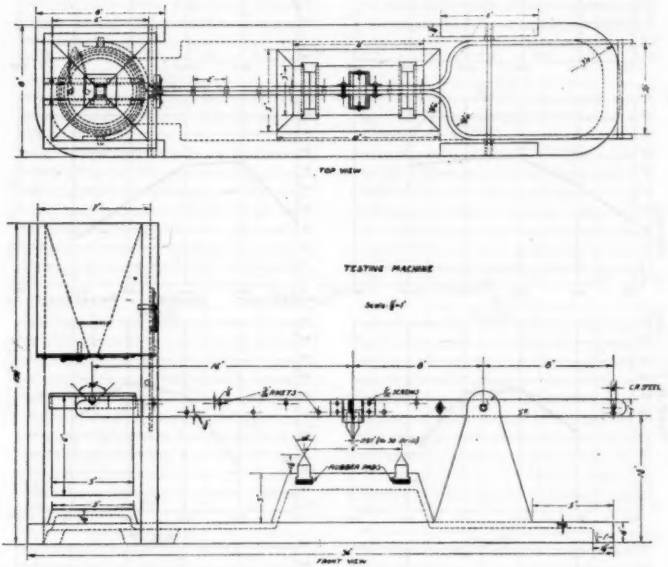

FIG. 2—SHOWING CONSTRUCTION OF TESTING MACHINE

As soon as the cores cooled to room temperature, they were broken on the transverse testing machine.

Results of Tests of Cores

Information obtained from cores made with the different oil binders was desired as follows: (a) maximum strength; (b) average strength over the best interval of 75 degrees Fahr.; (c) temperature at which maximum strength was obtained: (d) range

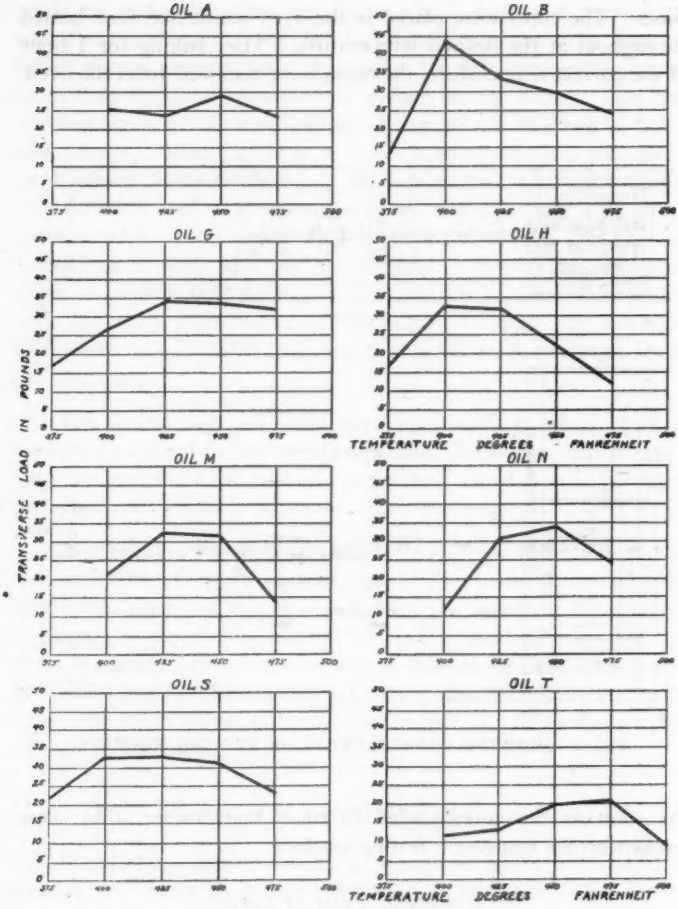

FIG. 3—CURVES SHOWING EFFECT OF BAKING TEMPERATURE ON STRENGTH OF CORES

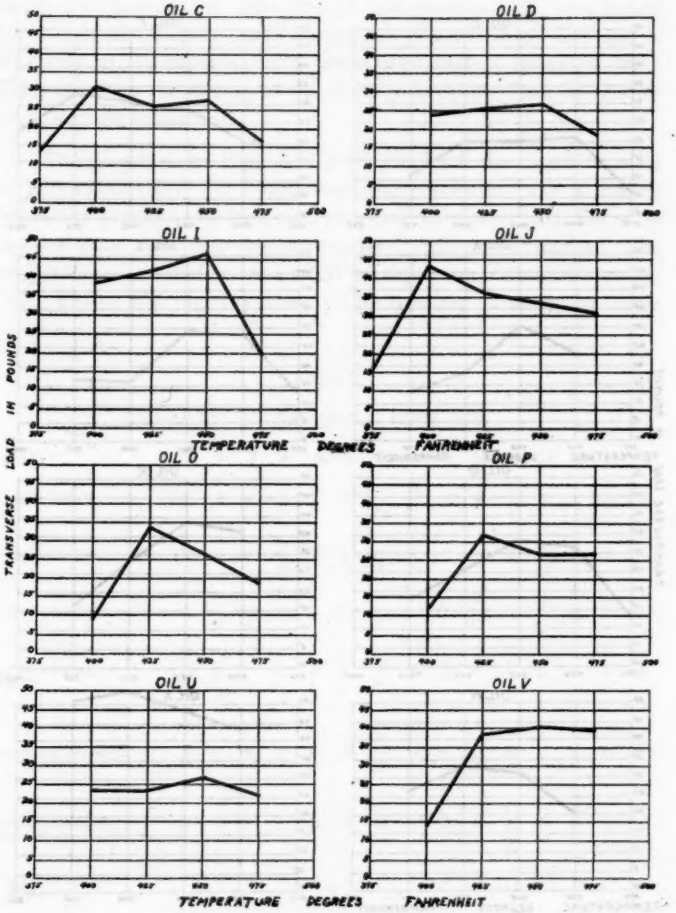

FIG. 4—CURVES SHOWING EFFECT OF BAKING TEMPERATURE ON STRENGTH OF CORES

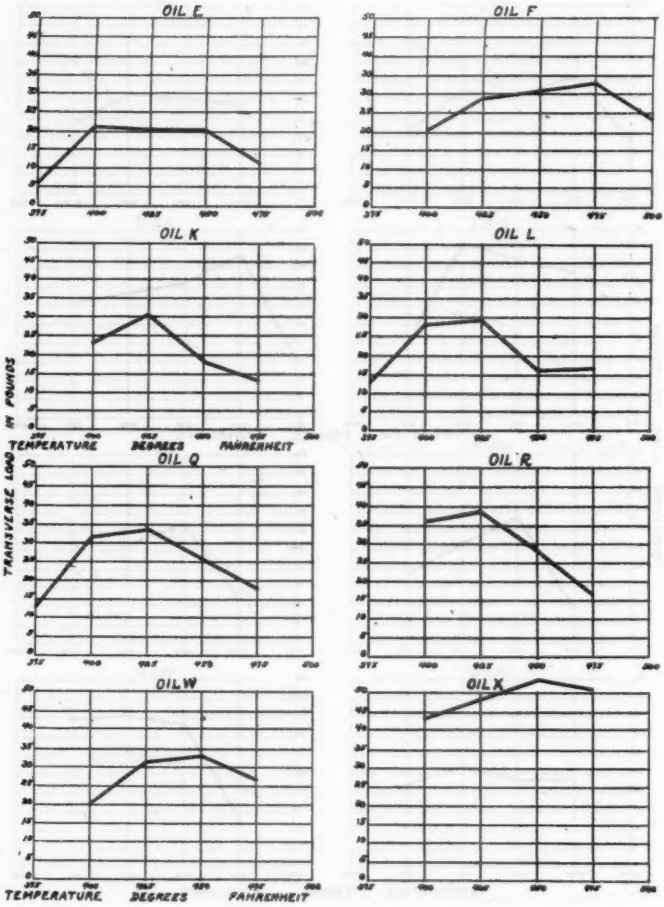

FIG. 5—CURVES SHOWING EFFECT OF BAKING TEMPERATURE ON STRENGTH OF CORES

of temperature over which high strength was maintained. The diagrams showing the strengths of test cores which were baked for 1 hour at different temperatures are given in Figs. 3, 4 and 5. Intervals of 25 degrees Fahr. were used in this series of tests. Each point on the curves is the average breaking load in pounds of 3 or more test cores.

The diagrams of Figs. 3, 4 and 5 indicate the characteristics of core-oil binders. It is apparent that some oils have a limited temperature range at which high properties are produced. Some oil binders have relatively low strengths at all temperatures. The temperatures at which maximum strength was obtained varies from 400 to 475 degrees Fahr. The bonding property of some

Table 2

QUALITIES OF COMMERCIAL CORE OILS

Quality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Specific Gravity	J S	B	V	G I	K L P	M	A O	H R X	N	F	T Q	W	C	D	E
Refractive Index	H	I	S	A K O	B J	L P	Q R	F T	G	M	N	D V X	C	W	E
Iodine Number	J	L X	K R	B I	G	O	F N	A	Q	C S T	D	E V W	M	P	H
Unsaponifiable Matter	L M N X	H V W	I	A C	B J	D	G S	K	T	P	F	Q	R	O	E
Maximum Strength	X	I	B	J	V	R	G N O Q	F H M S W	P	C	K	A L	U	D	E T
Average Strength Over 75° F.	X	I	V	J	B	R	G	S	F Q W	N	C H M P	A D L	K U	O	E T
Quality Decreasing to Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

core oils varies greatly with relatively small changes in baking temperature. It is interesting to note that different core oils may have the same characteristic strength curves such as oils B and J. Oil X is raw linseed oil.

Comparison of Properties of Oils with Strengths of Cores

In order to compare the chemical and physical properties of certain commercial core oils with the bonding strength of cores made with these oils, the test results have been classified into 15 groups in decreasing quality from left to right in Table 2. The highest quality is at the left and the lowest quality is at the right on the chart. By following one oil at a time it is possible to note the wide variations in relative quality when determined by different tests. Oils having high bonding property tend to have high specific gravity, high iodine number, etc.; also, oils with very low bonding property have in some instances inferior qualities as measured by chemical or physical tests on the oils. However, a close examination of the chart shows that there is no rule that any chemical or physical property of a core oil indicates the exact bonding property of that oil.

Conclusions

1. Commercial core oils are prepared from so many different drying oils and other materials having various chemical and physical properties, that it is impossible to establish the value of an oil as a core binder on the basis of any chemical or physical property of the oil.

2. The bonding property of core oils may be determined accurately by making test cores in a uniform manner, baking these cores under definite conditions and measuring the transverse strength of the cores.

3. The economic use of a specific core oil is possible only when the characteristics of that oil are known and the baking practice is controlled so that the maximum bonding effect of the oil is obtained.

Acknowledgment

This investigation of core oils was initiated and supported by the Detroit Foundrymen's Association. To this organization credit is due for promoting the development of standardized methods for testing core binders.

DISCUSSION

CHAIRMAN W. J. KIHN: This paper is of tremendous economic importance, and I feel personally that whenever we can get together enough data that we will be able to show to the man who is coming around and selling core oil to us, we will be able to save time for ourselves in the foundry, because I think we all like to treat courteously every man who comes around to see us. I know that many times I have given a core oil salesman time that I hated to spare very much.

S. R. ROBINSON: If Mr. Campbell was unable to get the percentage of linseed oil in these mixtures, I wonder if he could give us an idea of the cost of some of these different mixtures compared with the tensile strength, so that we could get a line on the efficiency of the different oils as to their cost.

CHAIRMAN KIHN: Your point is well taken. Professor Campbell has brought out that there are very many other factors connected with this problem and that at present they are only interested in the devising of test methods. The economic side, however, is the one of most importance.

H. L. CAMPBELL: As to the cost of these various core binders—we have no wish at all to introduce any commercial factors in this matter of developing standardized methods. We have no record of the cost of these individual materials. It is very true that it is an important matter when comparing the different binders, but if you just give it a little thought, you will see that we are not interested in comparing matters of cost. The main point of this first investigation was to determine if it would be possible to arrive at the bonding properties of an oil from the chemical or physical properties of the oil, giving no consideration to the brand or source of these samples. We merely pick up these samples of commercial binders as simply raw material in so many variables, 23 or 24 variables, and use them as the testing material. We did not consider the matter of cost, although in the matter of comparison for selection, it is of course a fundamental matter, the cost of the individual materials.

H. RAYNER: One feature Mr. Campbell will find difficulty in solving is the cutting action of the metal on the cores. I believe most will agree that linseed oil is considered 100 per cent efficient for making cores. We find that if we use raw linseed oil entirely and could get 100 per cent efficiency in mixing, we would get a much thinner film over the grains of sand. In this way we do not have the cutting action. Then, let me bring up the problem that Mr. Grubb brought up in paper at yesterday's session that the clay in the core soon absorbs so much of the raw linseed oil that it makes it too expensive. Therefore we use a less expensive oil in order to be sure we get the binder. This then resolves itself down to getting a good clean sand and the very best oil, an oil that will give a clean film and then you have ideal conditions.

H. L. CAMPBELL: Just a word about mixing core sand and oil; it is very important. In some of our previous manipulating of sand and oils and other binders we found that it was a quite difficult proposition to get a uniform mixture. We tried different ways of mixing, different types of machines, to be sure that every little particle of sand was uniformly coated with a very thin layer of bonding material. You will observe in the exhibit that we have here a mixing machine which is somewhat of the paddle type, though not exactly. I do not think you would call it a true paddle type machine, but it has a propeller in the pan that rotates about two different axes, one in the center of the pan and another on its axis, that gives a fine stirring action in mixing up those different binders with the sand. If you wish to use that type of a mixer in any of your plants, it is there for your consideration. It is the best type of equipment we have found for preparing small batches.

The matter of mixing core sand and oil is a very important matter. I have been trying to collect, during these meetings and from various sources, some accurate information, some facts on the uniformity of mixing oils and sand. I have not been able to learn anything definite as to the efficiency of the different types of equipment, that is, such as the pan or the paddle mixer or the type of mixer that is used by bakeries for mixing bread dough and other types of mixers. That again opens up another field to get some definite information on, namely, the efficiency of the different equipments used for mixing sand and oil.

S. J. FELTON: I am wondering whether anyone is interested in making an emulsion of oil and water before adding it to the sand? It seems to be very successful, provided the sand is clean sand with low clay content. One runs into a number of very useful points in foundry work, and I do not know who to give credit to for this, but it is an emulsion of oil and water to be made before mixing with the sand.

A MEMBER: Tell us how it is made.

S. J. FELTON: Warm water is best. Oil is placed in a barrel and the water is put in and you bubble the air up through the mixture. In that way the percentage of oil can be cut down enormously, but it only works well on clean, white sand with low clay content.

P. R. RAMP: That is the way we mix our oil; it gives a chance to spread the stuff all over. All we used is an old barrel, and we put so much oil and so much water in there and turn the air on it.

A MEMBER: I understand that to keep it in a permanent emulsion, it is necessary to add a clay. I wonder if any others have any information on that point.

H. RAYNER: We find that most of the products on the market will emulsify with water and that it can be obtained by adding rosin, which makes a slightly soluble oil.

Progress Report of the Committee on Refractories

To the Members of The American Foundry Men's Association:

Acting in accordance with authority granted at the 1924 Milwaukee meeting of this association, your committee through its secretary made the proper arrangements with the American Ceramic Society to meet with them at their annual meeting which was held in Columbus, O., February 19, 1925, where a special foundry program on refractories was in session.

By special arrangement with the officers of the ceramic society a meeting was arranged whereby the proposition of having the American Ceramic Society sponsor the formation of a Joint Committee on Refractories was presented. The meeting was called for Tuesday afternoon at 4:00 P. M. at the Ohio State University and those present were:

R. E. Kennedy, Asst. Secretary of the A. F. A.
R. F. Geller, Bureau of Standards.
Jas. Allen, International Harvester Company.
Ben R. Mayne, Saginaw Malleable Iron Co.
J. L. Cummings, Secretary of the Refractories Committee.
L. C. Hewitt, Acting Chairman for The American Ceramic Society.

R. E. Kennedy, acting as spokesman for the refractories committee of the American Foundrymen's Association, explained the work accomplished by The American Foundrymen's Association's Commmittee on Refractories and expressed the desire of the American Foundrymen's Association to have the American Ceramic Society sponsor the work of a joint committee, to act as a clearing house for the refractory problems and to form this joint committee consisting of members representative of the various societies as well as producers and technical men of the field.

After discussion relative to all angles and possibilities of such a movement The American Ceramic Society agreed to sponsor

and assist The American Foundrymen's Association in this work and appointed L. C. Hewitt as chairman to form a Joint Committee on Refractories, this committee to assist in the investigation and survey of the field, the standardization, simplification, methods of testing and specification of foundry refractories, including all branches of the industry.

In accordance with this authority Mr. Hewitt proceeded to outline the Joint Committee and to make appointments to carry on the work, and the following appointments were made:

American Ceramics Society	L. C. Hewitt C. E. Bales
American Electrochemical Society	J. T. MacKenzie
American Foundrymen's Association	C. N. Ring R. E. Kennedy J. L. Cummings
American Malleable Castings Association	G. L. Morehead
American Society for Testing Materials	F. A. Harvey
American Refractories Institute	M. C. Booze J. S. McDowell
Bureau of Mines	G. A. Bole
Bureau of Standards	R. F. Geller
Division of Simplified Practice	H. R. Colwell
Electric Steel Foundries Research Group	C. N. Ring
Institute of Metals Division, A.I.M.E.	
Steel Founders' Society of America	W. J. Corbett

Having completed the personnel of the Joint Committee, Mr. Hewitt proceeded to call a meeting to be held at Pittsburgh on September 14, 1925, at Mellons Institute, said meeting was called and held as per report attached.

Your committee begs to report that in order to further the interest of the foundrymen in general it has arranged to have a general meeting on Refractories at the Syracuse Convention Tuesday afternoon, October 6th, which said meeting constitutes the one now in session. Prepared questions were solicited and pub-

lished in printed form copies of which are now distributed among the members present and are now open for discussion.

In order to make the relations between The American Ceramic Society and The American Foundrymen's Association Refractory Committee more intimate it was recommended to A.F.A. that C. E. Bales of The American Ceramic Society be appointed to serve on our committee, which said appointment was duly made and Mr. Bales is now a member of this Committee.

The committee wishes to further report that due to other pressing matters W. A. Hull has found it necessary to resign from this committee, leaving a vacancy open for appointment. Recommendations have been made to A.F.A. to appoint Jas. T. McKenzie of the American Cast Iron Pipe Company of Birmingham, Ala., to fill this vacancy.

Respectfully submitted,

J. L. Cummings, *Secretary*,
Committee on Refractories.

C. N. Ring, *Chairman*.

Foundry Refractories

Steel, Malleable and Cast Iron Foundry Refractories

Discussion Session—Syracuse Meeting, Oct. 6, 3:00 P. M.

The session on foundry refractories at the Syracuse meeting of the Association will consist of a discussion of questions pertaining to practical foundry refractories problems covering the steel, malleable and cast iron branches of the foundry industry. The questions listed below have been submitted by members of the A. F. A. Committee on Refractories. It is desired that these be reviewed by members who are requested to present their viewpoints on these questions before this special session on refractories. Questions other than those listed may also be presented. Contribution can be made either in writing or by verbal discussion at the meeting. Written discussions should be sent to the secretary of the Papers Committee, R. E. Kennedy, 909 W. California St., Urbana, Illinois.

Steel Foundry Refractories

1. What effect does the rate of speed of heating up a new or a rebuilt furnace have on the life of the refractories? This question applies to open-hearth, electric, or heat-treating furnaces.
2. What is the best method of starting a fire in a new or a rebuilt open-hearth furnace to prevent excessive spawling of the brick?
3. Does the present standard test for spawling properties of brick really give any information? Does the test conform in any way with conditions met with in actual practice?
4. What are the requirements of good refractory bonding material?
5. Is uniformity as to size of refractory brick an important factor?

6. Is standardization of refractories, both as to size and shape, practical in the steel foundry industry?
7. Would standardization of sleeves, nozzles, stoppers, and runner brick be of special interest?

Malleable Iron Foundry Refractories

1. Of the various fuels used in firing malleable air furnaces, which is the most severe, and which the easiest on the refractories, both sidewalls and roof?
2. Does preheating the blast increase the tendency to shorten the life of the refractories by increasing flame temperature?
3. Is there any progress being made on the use of brick bottoms or other bottoms giving a longer life than the present washed silica sand?
4. Are brick bottoms economical?
5. Would it be practicable to lay up a brick bottom of thin joints grouted with fire clay instead of wide joints filled with sand?
6. Is greater economy secured through the use in bungs and sidewalls of a soft brick that melts or a hard brick which has a tendency to spall?
7. Should bung brick be laid up with or without mortar?
8. If bung brick are laid in mortar should they be straight or tapered?
9. Should sidewall brick be laid with thick or thin joints?
10. What is the best material for laying sidewalls of clay brick?
11. What are the most economical sizes of brick for sidewalls and bungs?
12. Is it profitable to insulate air furnace walls, bottoms and bungs to reduce the loss of heat by radiation?
13. If the melting point of a refractory could be increased, would it be possible to effect a saving by using a thicker wall and obtain a better fuel ratio? Is any work being done in this direction at the present time?
14. Of the various factors entering into the destruction of refractories, as chemical action of the slag, erosion of the gases, temperature of metal, flame temperature, wall thickness, kind of fuel, method of firing and others, which seems

to offer the best opportunity for saving? (It is the experience of some that the chemical action at the slag line causes the greatest trouble of all.)

15. What first causes failure of air furnace sidewalls in the absence of spalling, erosion due to the velocity of the furnace gases or eating away of the refractory materials by the slag?
16. What is the cause of spalling of brick as this occurs in the malleable melting furnace?
17. What are the various properties in order of their importance which a good bung brick should possess? The same for a good sidewall brick?
18. Have bauxite brick been used successfully and profitably for sidewalls and bungs?
19. What is the probable future development of bauxite or super-refractories?
20. Has carborundum been used successfully for sidewall bricks in daubing mixtures or in bottom mixtures and in what proportions?

Cast Iron Foundry Refractories

1. What kind of cupola bottom is cheapest consistent with best results?
2. What experience and results have been obtained with monolithic cupola linings as compared with block or fire brick linings?
3. What is the cheapest method of repairing linings on cupolas operating continuously all day? The discussion should bring out whether first or second quality refractories are used; also, kind of sand and quality and amount of fire clay used.
4. How much do your refractories repairs cost per ton of iron melted? What are the labor repairs per ton of iron melted?
5. How frequently is it necessary to reline from the top of the melting zone down, first, on continuous day run cupolas, and second, on one-heat-a-day cupolas.
6. Where a foundry is melting continuously and has a pair of cupolas, what is the experience with regard to repairs cost, first, to operate cupolas on alternate days—second, to operate one cupola from morning to late forenoon and then bring in the second cupola for balance of day.

Discussion—Foundry Refractories

CHAIRMAN RING: The purpose of this meeting is to have an open discussion of foundry refractories. The questions listed were questions submitted by men engaged in every day practice in malleable steel and in cast iron foundries.

You will remember at the last convention in Milwaukee the A.F.A. Refractories Section was instructed to approach the American Ceramic Society, asking them to sponsor a joint committee on refractories. This was done and the Ceramic Society agreed to sponsor this joint committee. The committee was called for its first meeting in Pittsburgh on the fourteenth of last month. The minutes of that meeting are available and we will have them read at this time.*

Instead of proceeding with the questions as listed, we will start out with malleable Iron Foundry refractories.

QUESTION 1: Of the various fuels used in firing malleable air furnaces, which is the most severe, and which the easiest on the refractories, both sidewalls and roof?

J. R. ALLAN: We operate a number of air furnaces around through the country and they are all hand-fired furnaces. It has been our observation that the hand-fired furnace is the most severe on refractories, particularly so if the wind-bung is not properly made and blast pressures are too high, for then you get considerable cutting action in the wind-bung and in the bungs next to it as well as the sidewalls. We believe the oil-fired furnace or the pulverized coal-fired furnace are much easier on the refractories, particularly the bungs and sidewalls near the frontbridge.

It would be interesting to hear what results the powdered coal fired furnace and the oil-fired furnace men are getting. I have a few figures from some of our various foundries on the number of heats per bung. Bungs last from sixteen to thirty heats, in the forward portion of the furnace near the bridge. In the rear portion of the furnace it is possible to get up to forty heats and over the firebox from forty to sixty heats. Refractories on the sidewalls, up near the front bridge wall, last anywhere from eleven to thirty heats. Variations come in from the different sizes of furnaces and method of firing. We have never been able to get them to average closer than that.

CHAIRMAN RING: I would like to hear from any using pulverizec coal or oil who can give us some information along this line.

A. S. WRIGHT: I might say, previous to two years ago, we operated entirely under the hand-fired method and we certainly were the bane of the brick men, it seemed. The hardest parts in our furnace were directly over the bridge wall and if we managed to average around eleven heats

*This report is printed on page 85.

directly over the bridge wall using solid roof type, 9 inches deep, we considered ourselves very fortunate.

Since going to the use of powdered fuel, I venture to say we have cut our brick costs practically in half. This in my opinion is due to the shortening of the period of firing. Under hand-fired conditions, an ordinary heat of thirty tons required fifteen hours from time of lighting to time of tapping. Under the use of powdered fuel that time has been cut to nine and one-half hours and that in my opinion is really the main point in the saving on the brick.

Another big item under the hand-fired proposition in our particular types of furnaces was the stack maintenance cost. Under the hand-firing condition, it was terrible. We used practically as many brick in our stacks as we did in the sidewalls due to the heat escaping up through the stack. Since the use of powdered fuel we have practically eliminated the stack maintenance cost.

QUESTION 2: Does preheating the blast increase the tendency to shorten the life of the refractories by increasing flame temperature?

J. R. ALLAN: I would like to ask a question: Does anybody here know of an installation where they preheat the blast air?

A. J. GRINDLE: Mr. Diesher, I am quite sure, has made some tests on that years ago. He ought to be able to give us some interesting information.

J. B. DEISHER: There isn't much information I can give you because of my business being in seventy-five foundries in the United States. There aren't any of them using heated blasts. I tried it but I didn't find a satisfactory method of heating the air. I believe, though, that it could be done. The arrangement that we tried was to put a series of pipes in our stack. These were cast iron pipes similar to boiler tubes. We found out after the pipes were in there a couple of hours they would burn out. There was carbon dioxide back in the firebox which didn't help much. I am sorry I can't give you more information about it.

C. E. BALES: I have been in a great many malleable foundries and I have never seen a case yet where they were pre-heating the blast. I feel sure if it were, it would shorten the life of the refractory walls and roof. You would have a higher flame temperature there and you would naturally soften the brick much faster than you do with a cold blast.

A. J. GRINDLE: I don't think there are any malleable foundries now pre-heating their blasts. Theoretically, we would save 20 to 25 per cent of the fuel, but when using pulverized coal a higher temperature might melt the brick.

QUESTION 3: Is there any progress being made on the use of brick bottoms or other bottoms giving a longer life than the present washed silica sand?

J. R. ALLAN: I would suggest maybe Mr. Colburn could give us something on his furnace bottoms at the Auburn works.

E. COLBURN: We have to renew these bottoms every time we build the furnace over. We are getting about sixteen or seventeen heats. I never have seen the brick bottoms tried.

J. H. SCHMUCK: Over a period of the last two and one-half years, we have gone rather extensively into the proposition of what we call combination bottoms, that is, brick bottoms filled in between with some sort of silica sand, Ottawa white silica, or some of the sands we have in the east. We found we got a great difference in the life obtained from these bottoms. From some bottoms we were able to get as many as forty-five to sixty heats before they had to be renewed and from the next bottom we put in we would get perhaps fifteen heats. The iron would go down underneath parts of the bottom.

After trying it, as I say, for the last two and one-half years, we went back to the use of silica sand bottoms again because when the iron got under the brick it caused trouble. The scabs of iron getting around the brick, washing out the sand, caused a great deal of trouble in repairing the furnace.

If any of the men from any of the western malleable foundries are here, I would like to hear what some of them have to say because I know a great many of them have been using combination brick and sand bottoms.

J. R. ALLAN: Mr. Chairman, in some of our western malleable foundries, we have substituted bank sand for wash silica with equal or better results. We found it a very cheap substitute.

QUESTION 6: Is greater economy secured through the use of bungs and sidewalls of a soft brick that melts or a hard brick which has a tendency to spall?

F. HARVEY: The way that question is worded, it seems to me it is misleading, speaking from the brick manufacturers' standpoint. A soft brick and a hard brick may be made of the same clays and may have the same melting point, but there would be considerable difference in their performance. A brick which has a lower fusion point and will melt or run, may be hard or soft, according to the method of manufacture. So it seems to me the question is misleading to that extent. If we speak of soft and hard as referring to burn, I think the general experience of the brick manufacturers is that the soft burn brick in the bung gives the longest life.

E. A. GRINDLE: In our foundry we use what we call the malleable brick, nothing else, straight, malleable type, for bungs, sidewall and all. We make no distinction. By running tests, and from our experience, we had to get away from the soft brick. We never could find anything that would do the work as well as the hard brick, in our experience. If any of you fellows want to see it, come over to our plant of the International Harvester Works at Chicago.

C. E. BALES: This question is misleading as Mr. Harvey brought out. The brick which is the most economical to use is one that won't spall. I have been in a lot of malleable plants where they have mighty severe conditions and never yet have I seen a case of brick melting. The usual failure we run across is simply a case of erosion. When the roof brick seems to melt more often it is a case of ash in the flame being blown up against the bung, attacking the brick and giving it the appearance of melting. The most economical brick to use in a malleable bung is a brick that does not spall.

J. W. BOYWID: I have had bricks on the bridge and the sidewalls eaten away into the second layer before you knew it. The flame would eat that whole row right off. Call it spalling if you like, or call it whatever you choose, but the brick is gone. If you get a brick straight in line, you are getting fair satisfaction for a time. If you get brick not laid properly, you get gullies; it isn't altogether the brick, but if you have the brick laid well, and it burns away, you are getting poor service from the brick.

E. A. GRINDLE: I would like to ask the gentleman just what he means by laying brick well.

J. W. BOYWID: Close and straight.

E. A. GRINDLE: Do you use anything between them?

J. W. BOYWID: We put them as close together as possible so they will be free from joints.

C. E. BALES: One of the things we frequently find in foundries is the use of inferior mortar. In a great many cases we find they are using high grade brick. With some of the best brick produced in the United States—those of Pennsylvania, Kentucky or Missouri—you will find they are using as cheap clay as they can possibly get a hold of. There are a great many other so-called patented refractory cements on the market which certainly will cause you a multitude of trouble.

I am very glad Mr. Boywid brought out the point he did about brick eating away, but I believe before this round table discussion is over, we will have pretty well decided that it isn't melting; it is simply a case of chemical erosion, that is, slag or metal eating the brick up.

QUESTION 9: Should sidewall brick be laid with thick or thin joints?

J. S. MCDOWELL: It seems to me that possibly one thing in the mind of the person who asked Question No. 6 has not been entirely answered. What he intended to ask was probably whether or not a highly refractory brick is essential for use in bungs for he speaks of the soft brick which melts and the hard brick which spalls. I think it has been the experience of most malleable people that the brick should be a highly refractory one. I don't know of any brick which is being used on a large scale which has a fusion point lower than that corresponding to cone No. 31.

CHAIRMAN RING: We will go back to Question No. 9.

C. E. BALES: From the observation I have made at different malleable foundries, the places where they get the best results they lay them up with very thin joints, the thinner the better.

CHAIRMAN RING: I believe that has been the experience of practically everybody. If anybody has had experience to the contrary, we would like to hear from them.

E. A. GRINDLE: We have had that experience from our sidewall or the bung line. As we get up toward the top, we lay them up just as if we were piling brick, tight, close together. You start your fire and you don't have any cracks.

CHAIRMAN RING: Question No. 10: What is the best material for laying sidewalls of clay brick?

W. J. BOYWID: We experienced considerable trouble with different kinds of clays until we got a clay which stands heat as well as the brick does. Since then we had pretty good results.

QUESTION 11: What are the most economical sizes of brick for sidewalls and bungs?

J. R. ALLAN: I think the standard series worked out for sidewall brick are probably all right at the present time, but I know there are a number of malleable foundries around the country that order special sizes of bung brick. I believe future practice is going to show this impractical and eventually they will all get to use a standard bung brick. I know in some of our own foundries we probably have fifteen or twenty different sizes of bung brick. They are gradually being eliminated to the standard 101, 103 and 105 series.

W. J. BOYWID: I believe the foundry that finds the use of double bungs of any advantage want brick to match it. The foundry that uses single bungs can get along with any standard size. They can use 13½ as well as 13 inches.

QUESTION 12: Is it profitable to insulate air furnace walls, bottoms and bungs to reduce the loss of heat by radiation?

CHAIRMAN RING: Has any one present operated a furnace as stated in this question? I wonder if some of you refractory men could give a theoretical answer to that question?

DR. F. HARVEY: From a theoretical consideration, it seems it should be possible to insulate the bottom but not the sides or top. The bottom can't reach a temperature higher than the temperature of the bath and that shouldn't be high enough to cause the refractories to melt. Both the sidewalls and tops reach temperatures above the bath and close to the melting point of the refractory. The minute you insulate them, they are going to melt.

J. T. MACKENZIE: I had a friend who wrapped asbestos sheets around the melting zone of his cupola. They ordinarily had been running months without relining but when insulated they burned it out in three hours.

QUESTION 13: If the melting point of a refractory could be increased, would it be possible to effect a saving by using thicker walls and obtain a better fuel ratio? Is any work being done in this direction at the present time?

That appears to be a question that some of the refractory men ought to be able to give us some information on. We don't seem to be able to get a response from the refractory men. I wonder if any of the manufacturers can give us any experience along this line?

J. R. ALLAN: Maybe some of the refractory manufacturers can give the meeting an idea of the average wall thicknesses they find used around the country. I know in our own plants, the wall thicknesses run from 13½ up to 22 inches.

A. J. GRINDLE: I get around to a great many of the malleable foundries and it seems an 18 inch sidewall is the most economical and most popular, the one big reason being that the outer 9 inch wall will hold the iron in case the inner 9 inch burns away. If the inner 9 inch wall could be made to stand more temperature and last longer, I think 18 inch wall would be all that would be necessary.

C. E. BALES: I don't know of any work being done along that line. If it were possible to have a refractory with a higher melting point, I don't know whether you could have any better fuel ratio or not. If you use a thicker wall, the heat you are now losing would be stored up in that wall. It would be questionable if you would get better fuel ratio or not. Another thing, I don't believe you could get a refractory with a higher melting point than you get at the present time, unless the price was prohibitive.

J. R. ALLAN: Is there anybody here who has had any experience with chrome brick in sidewalls?

W. J. BOYWID: I happened to go into a malleable foundry not very long ago and the man told me he used some chrome brick for trial, but to his sorrow he couldn't anneal the casting, so the brick was taken out very quickly.

QUESTION 14: Of the various factors entering into the destruction of refractories, such as chemical action of the slag, erosion of the gases, temperature of metal, flame temperature, wall thickness, kind of fuel, method of firing and others, which seems to offer the best opportunity for saving? (It is the experience of some that the chemical action at the slag line causes the greatest trouble of all.)

CHAIRMAN RING: That is a rather comprehensive question. We might be able to get some discussion along that line. That is a question that ought to appeal to the users of refractories. They ought to be able to give us some information from their experiences. Can anybody offer anything at all?

C. E. BALES: I believe that the biggest opportunity for saving would be to get a brick that is more resistant to the chemical action of the slag. I have seen more failures of sidewalls due to that one thing than anything else. I would say that during the last year our laboratory has done some work on the action of malleable furnace slag on brick. We have found there is considerable variation in the chemical composition. So far it seems those slags that contain the highest iron content are the most destructive to brick. I believe that the foundrymen could prolong the life of their brick somewhat if they could control the composition of their slag. I know we helped out one company along that line. They were having difficulty with sidewalls eroding away and they had a pretty high iron slag. We found they were using excessive blast. When they cut it down to where it should have been, their difficulty ended.

A. J. GRINDLE: I think that the general experience of all the companies using pulverized coal will bear out this gentleman's remarks because there is no top blast on the successfully operated melting furnaces using pulverized coal and there is a steady reducing flame at all times with no excess air to speak of.

We have noticed in many of the late installations that the slag line does not burn out any more than the other part of the wall above the metal due to the reduced oxidation of the metal and the change in the chemical contents of the slag.

CHAIRMAN RING: I think that was a very interesting comment, Mr. Bales made. I think it is a difficult thing to classify a refractory as suitable for certain purposes when its practice hasn't been standardized, when the condition varies from day to day. I think that is a fact not only in malleable practice but all metallurgical practices. This is one thing the foundryman has to learn in order to get suitable refractories. He has to standardize his practice to meet the requirement of those refractories.

W. J. BOYWID: I would like to ask Mr. Bales what he means by excessive blast. Can you give us a line as to where the "excess" comes in?

C. E. BALES: I can't, because it varies too much. What one fellow considers a correct blast, the other fellow thinks isn't enough. You can tell by the amount of slag you have and the chemical composition of your slag. The first thing the foundryman ought to look for is, do the brick burn out sooner than you think they ought to.

W. J. BOYWID: You couldn't say where the right line is. I wanted to find that spot. That is what I am looking for.

A. J. GRINDLE: I might give you some information on excessive blasts. I think excessive volume has more to do with the oxidation, or the burning out of the brick, than excessive pressure. I know the American Radiator company used to fire with hand-fired furnaces with one-half ounce pressure with quite a large volume. I know other plants using as

high as twelve ounces blast pressure and getting better results out of the brick work because their volume was low and their fireboxes smaller. It is the air that affects the brick more than the volume of pressure.

QUESTION 17: What are the various properties in order of their importance which a good bung brick should possess? The same for a good sidewall brick?

CHAIRMAN RING: I know the foundrymen are looking to the refractory men to educate them on refractory problems. The foundrymen haven't been up on refractories to the point they should have been.

J. S. MCDOWELL: It isn't possible, probably, to give very exact information regarding all of the factors. Bricks of different kinds are giving fairly good service in the malleables. Nevertheless, I think there are a few properties which they all possess. I doubt if there are any bricks which are giving very good service that are not of good refractoriness. There are few, if any, good bung brick which melt below cone 31. All of the bricks which give good service in bungs are resistant to rapid temperature changes. Then, too, most of the bricks which give good service are of fairly high porosity. I don't know of any brick of extremely low porosity that is a suitable malleable bung brick. I don't know where the limit comes. Of all the brick with which I have had experience, about 18 per cent seems to be the lower limit. Highly silicious brick are not, so far as I know, being successfully used. I know of no brick of greater than 58 or 60 per cent silica that are giving good service in bungs. That, of course, does not define very accurately all that a malleable furnace brick should be, but it does point out, possibly, some few of the outstanding properties.

C. E. BALES: On the sidewall brick, I think the important thing there is sufficient refractoriness and low silica content. On that, I think the best brick have been about 52 per cent silica. I have seen some which ran around 65 to 70 per cent silica that were eaten away within two or three days. A brick for sidewalls should be fairly resistant to temperature changes, although they don't have to be as good in that property as bung brick. But if sidewall brick do spall, they cause you as much trouble as if they spall in the bung.

A. S. WRIGHT: I don't know what the experience is of the ordinary malleable foundries, but I know we found the brick that stands in the roof is adaptable to the sidewalls. It has been our experience over the last ten years that the same brick is good for roof and sidewalls.

W. J. BOYWID: During the past year, I have tried out probably fifteen different kinds of brick to meet my own requirements. I won't mention any of the names, but I did find an awful big variation. I had some brick that lasted as long as seven heats. I just practically finished with all my experiments. Naturally, the brick that gives me the most heats is the brick we are going to order.

J. S. McDOWELL: There are a few malleable furnaces that seem to defy the general rules applying to brick for bungs and sidewalls. I believe that probably ninety per cent of the brick for bung purposes are soft burn brick, but there are a few companies which consistently get better results from hard burn brick than from soft burn. Why that should be, I have no idea.

J. H. SCHMUCK: After experimenting in different grades of brick for the bungs, we find softer brick for the bungs and harder brick for the sidewalls seem to give the maximum life attainable. Harder brick seems to withstand the action of slag better than the softer brick. The softer brick in the bung seems to give better life than the harder.

QUESTION 19: What is the probable future development of bauxite or super-refractories?

CHAIRMAN RING: That is another one of the large questions which we may be able to get some discussion on probably from the refractories men.

J. S. McDOWELL: I think it is highly probable some of them will give you satisfactory service. However, they will necessarily command a greater price and whether or not they will be worth the additional cost is something you can determine only by experiment. They will cost three to four or five times as much as fire-clay brick.

C. E. BALES: I think when you mention super-refractories here, you have in mind high alumina refractories. I don't know of a single case where they have given as good service as ordinary clay. I know a lot of companies who have tried them and they say they fail from spalling. They have to burn them extremely hard and when they do, they increase their susceptibility to temperature changes. Therefore, there is spalling.

J. S. McDOWELL: With bauxite, I have known of one or two trials in which they did not give particularly good service, not as good service as the much cheaper clay they were intended to replace.

QUESTION 20: Has carborundum been used successfully for sidewall bricks, in daubing mixtures, or in bottom mixtures, and in what proportion?

A. S. WRIGHT: I might say that we have made use of the carborundum firesand in our daubing mixtures. We used to use mixtures of firesand and of ordinary fireclay. It was necessary each day to daub the furnace along the slag line. It would eat in on brand new brick as much as three or four inches. Since the use of carborundum firesand (and I might say we use it in very large proportion—one to one—one part of carborundum and one part of clay) we find one larger application of that with successive applications of very small amounts where there has been slight eating at the slag line, that our problem of eating in on the slag has been practically removed by the use of carborundum.

J. H. SCHMUCK: We have used the carborundum firesand and also for daubing mixture, but we have been able to use it more dilute than the mixture of one to one. We have been able to keep a patch on the slag line in our twenty-ton malleable furnace from one end of the week to the other without having any apparent effect at all while the brick on both sides of it will be eaten right in.

DR. F. HARVEY: One statement on the other side of the question. I was in a malleable iron plant last week where they told me after extensive use of various expensive patented cements and daubing mixtures, they found properly prepared fire clay did the same trick and they had abandoned the use of the patented mixtures.

CHAIRMAN RING: We will proceed to the questions submitted by the Cast Iron Foundry Refractories Division.

QUESTION 1: What kind of cupola bottom is cheapest consistent with best results?

W. J. BOYWID: We find the gangway sand gives us the best results. I don't know of anything cheaper.

QUESTION 2: What experience and results have been obtained with monolithic cupola linings as compared with block or fire brick linings?

J. T. MACKENZIE: The only experience I had with monolithic lining has been in the melting zone. We practiced ramming the fire clay, sand, and crushed fire-brick mixture. In the old days, when we had refractory fire-clay without any plasticity, we had to use yellow clay and the results were unsatisfactory. But lately, in an experimental cupola, I have used a mixture of much more plastic clay where I have to use but 25 per cent clay and 25 per cent fire sand with 50 per cent crushed fire brick of very good quality. Up to about four feet above the tuyere you get a most beautiful line, no joints, it did not crack on cooling down with water, and the erosion (or corrosion, or melting away of the lining) was only about one-third that of the usual lining with fire brick. But beginning at about three or four feet above the tuyeres, where the mixture did not attain sufficient temperature to get a good burn, the lining was very poor indeed and even on such charging (as in the experimental cupola) the top has almost entirely failed so that we have come to the conclusion that the monolithic rammed-in lining will be fine for the melting zone but worthless above that zone.

J. R. ALLAN: I would like to find out what size cupola Mr. Mackenzie uses and how long it takes to put in a monolithic lining.

J. T. MACKENZIE: I had a twenty-seven inch shell for the test and had no trouble at all in ramming it in with a pneumatic rammer. I shouldn't anticipate trouble on any size. I never tried it on large size cupolas. We had no trouble ramming it.

CHAIRMAN RING: Any further discussion of this question? If not, we will take up question No. 3: What is the cheapest method of repairing linings on cupolas operating continuously all day? The discussion should bring out whether first or second quality refractories are used; also, kind of sand and quality and amount of fire clay used.

P. KWASINSKI: The cheapest method I have found in my experience is to use what we call sandstone. We take and fill in partly with fire brick and we finish up with this cheap sandstone. We find we get very good results and that is about the cheapest I know of.

H. RAYNER: I find the cheapest method is to reline our whole melting zone each day, that is, it is relined about the tuyeres where it is eaten in. It is only eaten in to the extent of 2 inches; that is, in the sixty inch cupola and we melt 160 tons in nine hours.

P. KWASINSKI: I would like to ask that gentleman if that isn't expensive, to reline every day. I have been melting 160 tons in ten hours and we find the lining was burnt out very much. We have lined it partly with sandstone and fire brick. I would like to ask this gentleman how much it costs him to reline that melting zone.

H. RAYNER: That could be answered if any one knew how much brick it takes. We just take the brick from the pile. I have no comparative costs. You could tell by the amount of brick it takes for a sixty inch cupola which is about three feet in height.

F. H. GULDNER: We were using fire brick up until a short time ago for 77 inch cupolas, running 120 tons in eight hours and the cutting in those bricks, in the melting zone used to be about four or six inches deep. That cutting was repaired every day with ordinary fire clay.

H. RAYNER: I would like to ask what kind of sandstone Mr. Kwasinski used a local material?

P. KWASINSKI: Just ordinary grindstone.

H. RAYNER: Do you let the iron come in contact with that?

P. KWASINSKI: Yes, it is mixed in with clay.

DR. F. HARVEY: I would like to make a remark that perhaps will start something. We were talking a minute ago about the cost of fire clays for malleable iron furnaces and some one remarked he didn't know where they got their fire clays. Most foundries buy clays locally for about one-third what it costs the refractory manufacturer to produce his high grade clay. In simply watching the repair of cupolas as it goes on every day, from my standpoint, I don't see what good it does at all. A man takes a No. 2 split or No. 1 split fire brick and plasters it with a cheap fire clay against the side of a partly glazed wall. He might as well leave it out in the first place.

J. T. MACKENZIE: If you every try cheap daubing material, you will see how quick the cupola bungs up. Buy a good clay and you will see the difference; it is astonishing. We used to run sixteen hour heats (seventy-two inches inside diameter cupola), and when we dropped the bottom, if there was anything left in it over the tuyeres, we had to pick that out. Now we have good clay and the cupola looks almost like it is chipped out. The pressure gauges used to start out on eight, nine, ten ounces and climb from the beginning of the heat until they wound up between eighteen and twenty ounces. With good clay daubing they start out eight to ten and when they finish they may be at eleven and once in a long while they may be at twelve. The absence of bridging is most noticeable. As the gentleman says, the cutting in the melting zone is almost gone. I think one of the prime things in a good daubing mixture is to have a highly plastic clay of good refractoriness. You can see brick still intact after a ten or twelve hour heat.

H. RAYNER: I agree with Mr. Mackenzie. Your daubing material should be equally as good as your brick—if anything, better—because it gets abused in the process. We have had experience with that where the brick had fallen right way.

CHAIRMAN RING: It is reasonable to expect, if you are going to lay up high class refractory brick, that it is foolish to lay it up with inferior material.

QUESTION 5: How frequently is it necessary to reline from the top melting zone down—first, on continuous day run cupolas, and second, on one-heat-a-day cupolas?

J. T. MACKENZIE: Our relining of the melting zone is a continuation of the relining of the glazing zone. We don't reline the melting zone at all. Only when the top brick is worn out do we go ahead and repair the whole thing.

W. J. BOYWID: In some cases we have run a cupola for thirty years and never had to reline it all the way to the top. We just relined it where it was needed. I don't know how long it will last. I believe it is still running the same way.

CHAIRMAN RING: The next is question No. 6: Where a foundry is melting continuously and has a pair of cupolas, what is the experience with regard to repairs cost—first, to operate cupolas on alternate days; second, to operate one cupola from morning to late forenoon and then bring in the second cupola for the balance of the day.

H. RAYNER: Why would a person want to use two cupolas if they can get the tonnage per hour that they require on one?

P. KWASINSKI: When I was melting 150 to 160 tons a day and going along into heat, we would have to decrease and by running two cupolas we found that we could use a cheaper grade of iron.

H. RAYNER: I meant as far as cupola practice is concerned. It would help to cheapen the mixture?

P. KWASINSKI: That is, as far as refractories is concerned. That has been my trouble. The cupola was burning out too much, so we got busy and ran both cupolas. As I stated before, we could run cheaper iron.

CHAIRMAN RING: If there is nothing further on this question we will take up briefly the questions on Steel Foundry Refractories.

QUESTION 1: What effect does the rate of speed of heating up a new or a rebuilt furnace have on the life of the refractories This question applies to open hearth, electric, or heat-treating furnaces.

F. T. ASCHMAN: In my experience as consulting chemist, I find one of the main troubles about heating any kind of a furnace is the lack of precaution to get the lining dry. It seems to be that in many cases, in the haste to get the furnace lit up, moisture is left in the lining. With such heating up the lining naturally gives way. I have been consulted on two or three different occasions where trouble was experienced with spalling or breaking away of the silica lining and which was traced afterward to simply a lack of drying-out of the lining before heating.

MR. DEVONEY: How should the lining be dried? The moisture won't get out if you don't use fire in it.

P. KWASINSKI: I would like to ask Mr. Aschman a question: How much time does it require to dry out a lining in a cupola, for instance? What do you consider a good time to make a fire in a cupola?

MR. ASCHMAN: The length of time required for drying out will vary according to the lining, but by heating up slowly and watching the lining until steam ceases to appear at the stack it is a pretty good indication. You can't give any special length of time because of the difference in the linings, difference in the thickness, and the kind of lining. I have reference especially to a case where a silica brick manufacturing concern had trouble repeatedly from the same concern. Finally, they sent a representative up to find out what was the matter and they found it was simply the haste in trying to dry up and start up. Afterwards, by cautioning them to start slowly, I think they put in a day or more and then they were all right.

CHAIRMAN RING: Question No. 2: What is the best method of starting a fire in a new or a rebuilt open-hearth furnace to prevent excessive spalling of the brick.

DR. F. HARVEY: I can't answer the general question of the best method of heating up open-hearth furnaces, but it is a generally known fact among those manufacturing silica brick that the most essential point is to keep it going. Where you get into spalling troubles in starting any furnace is in letting the temperature vary up and down. There is a critical point for silica brick which is around 270 degrees to 300 degrees

centigrade where it is a great deal more sensitive to spalling than at any other temperature. It should be brought slowly but steadily through that period. Beyond that, it doesn't make any difference.

CHAIRMAN RING: Do you figure it makes any difference where you build a wood fire? It has a high flame instead of a low dead heat. Your flame impinging against the sidewalls and roof have dire effect on it from the standpoint of spalling, although the temperature may not be high.

DR. F. HARVEY: I haven't the practical experience to answer your question. From the theoretical standpoint, it certainly would. Mr. McDowell knows more about open-hearths than I do; perhaps he could tell us.

J. S. MCDOWELL: I really haven't as much experience in the open-hearth as Mr. Harvey believes.

In one of the large steel companies, with seventy-five ton open-hearth furnaces, they had considerable trouble constantly with spalling which they ascribed to the quality of the brick. It was found upon investigation that after a furnace was rebuilt they piled wood, old railroad ties, etc., into the hearth and lit them up and brought the furnace up to operating temperature as rapidly as possible. Under those conditions, they were getting a life of sixty heats from the roofs, which is not particularly good. We would consider the average life of an open-hearth roof as well over 200 heats and, in some instances, higher than that. It was suggested they take more time and that the fires be built in such a way that the flame would not strike the sidewalls nor the roof, and that the rise of the roof be watched so that excessive stresses would not come on the brick. With the first furnace treated in this way, they got a life of two and one-half times their preceding average. They then decided that possibly the brick didn't have everything to do with it after all and continued experimenting upon the way the furnaces should be heated up in their particular practice. I believe they are now getting good service from the brick they had formerly condemned.

CHAIRMAN RING: Mr. McDowell has given a complete answer.

S. R. ROBINSON: Some years ago, in the Pittsburgh district, we used to heat up an acid furnace of twenty-five tons with a gas flame (natural gas) for twenty-four hours, and then with a slow wood fire before putting on the natural gas or oil. We felt at that time that the critical point on the expansion of the roof was around 1400 degrees F. We were very careful to allow for that expansion by letting the roof out so it wouldn't rise.

J. S. MCDOWELL: One point might be added to what Dr. Harvey says about critical temperature. While in heating the hot end of the brick may have passed the sensitive point, 270 to 300° C., the interior of the brick may still be a lower temperature and practically I think it is very good not to heat or cool silica brick rapidly unless they will glow in the dark. Above dull red heat they can be heated and cooled rapidly without doing damage. Below a dull red heat, great care should be taken.

MR. DEVONEY: I have seen very little spalling on electric furnaces where we have brand new roofs. As a matter of fact, we have rammed the furnace and not bothered whether it was going fast or slow and we would have no trouble at all.

J. S. MCDOWELL: In various furnaces, the experiences of the operator may appear to contradict what has been said, but I believe in most of those furnaces it will be found that the roofs are dome-shaped and that what has been said about the rapidity of heating and cooling in an ordinary arch doesn't apply, at least not in the same degree.

MR. DEVONEY: I might say they are quite big blocks, not the ordinary bricks.

J. S. MCDOWELL: The dome-shapes very often hold pieces of brick that have cracked. I have seen a good many instances where brick had actually cracked several inches inside of a hot furnace and where the particles hadn't fallen out on account of the effect of the dome. In an ordinary arch, they might come out.

QUESTION 3: Does the present standard test for spalling properties of brick really give any information? Does the test conform in any way with conditions met with in actual practice?

CHAIRMAN RING: I think that is a question that can be taken up by the Joint Committee on Refractories. We thought a discussion on it now might be helpful.

QUESTION 4: What are the requirements of good refractory bonding material?

MR. ASHMAN: It is evident that good bonding material must have a resistance to heat equaling that of the lining itself and it also must have the property of being so fusible that it will glaze over and that some of its fused substance will enter into the brick and cause them to be bound together, but not with too much fusibility to prevent its being a refractory.

QUESTION 5: Is uniformity as to size of refractory brick an important factor?

CHAIRMAN RING: That question was discussed under malleable practice and that which applies to malleable applies to steel practice. I think it is the consenus of opinion that uniformity of size is desirable.

C. E. BALES: I think it is very desirable, as you say, to have brick as nearly uniform as possible. But I don't think it is necessary to have them as uniform as the foundryman sometimes asks for. The American Refractories Institute is now going into that subject and we will probably know more by the time we have another round table discussion. What we are trying to find out is, just what tolerances the brick made at present has, and how close we can come to that. It is impossible to make

brick that are absolutely uniform in size. I know of some consumers who don't allow you on thicknesses any more than a sixty-fourth of an inch. You can't make fire brick that close.

CHAIRMAN RING: They don't lay them that close, do they?

J. S. MCDOWELL: I knew of a case that later changed to a thirty-second of an inch. The original specification was a sixty-fourth, but the company using brick found they couldn't get much material and changed it to a thirty-second. When the brick bought on that specification arrived, they found only 80 per cent of them passed.

J. R. ALLAN: Of course, it is desirable to have brick to the closest possible limits. However, I never saw any of the manufacturers get much closer than an eighth to three-sixteenths on length and a sixteenth plus on thickness. The width I don't think makes so much difference. There is one thing the refractory manufacturers can do, and that is, to keep the brick straight. Take bung brick particularly, 13½ inch brick. Clamp those up in a bung and, with many brands of brick, you will find from 40 to 75 per cent cracked after you put the pressure on the bung. This induces spalling and rapid destruction. The manufacturers have a problem there, keeping their brick straight.

CHAIRMAN RING: We will take up the last question: Would standardization of sleeves, nozzles, stoppers, and runner brick be of special interest?

That is a question to come before the producers. I think it will be taken up. Any comments? If not, that will conclude the business of the meeting and we will stand adjourned.

Safety in the Foundry†

By R. G. Adair,* Middletown, O.

It is estimated that industry suffers the loss of one billion dollars annually through time lost on account of accidents. Of this vast waste the foundry contributes relatively more than its share as is indicated by the fact that during 1924 the foundry division of the iron and steel industry had almost twice as many accidents per million man-hours as did the great steel plants of the country. Likewise the severity of foundry accidents was greater than that of the steel plant division. To those sincerely interested in the safety of working organizations, this is startling information, and indicates the necessity for concentrated effort on the part of foundry executives and safety engineers to bring about a marked reduction in foundry accidents.

Volumes have been written upon the subject of safety in the foundry. Many ideas have been presented and many experiments tried with the natural result that the many and unworkable theories have been largely eliminated, while a few time tried ideas have been retained and are functioning most satisfactorily where given a thorough trial. I, therefore, realize that many of you gentlemen may be as fully conversant as am I with this catalog of remedies and I shall ask your indulgence, if I repeat a great many things with which some of you are familiar.

In order that one may proceed intelligently on the reduction of foundry accidents, it is most important to be able to visualize the cause. No better method can be pursued than through a careful analysis of accident statistics, both as applies to the industry in general and, where accurate records are available, to the local operation in particular.

An analysis of 1,176 lost time accidents in the foundry industry recently made by one of the large insurance companies reveals that 87.1 per cent were due to non-mechanical causes and that burns and the handling of material predominated in this class. In

†Contributed on behalf of the Ohio Foundrymen's Association.
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fact these two items constituted 50 per cent of the non-mechanical causes. Therefore, if foundry managers, safety engineers, foremen, and others would concentrate their attention on the causes of burns and the long list of injuries resulting from material handling, it is reasonable to expect that foundry accidents would almost be cut in half.

Burns

Foundry burns are usually caused by hot metal and perhaps no one item can be more effective against this class of accidents than the matter of good housekeeping. Well defined aisleways should be maintained at almost any cost and the working organization be made to understand that such aisleways are for traffic purposes and not for parking. Obstructed floors over which molten metal is transported and obstructed aisleways and gangways over which molders and helpers walk should be free from tripping hazards and offer an unimpeded means of escape in case of a hot metal spill. It seems almost unnecessary to state that crane and hoist cables should be subjected to the most rigid inspection and be changed promptly when found to be defective, yet the failure to follow this practice results in many of the most serious foundry accidents. Men following a heavy ladle of molten metal have but the most meager chance to escape with their lives, if through the failure of a crane cable or hook the entire mass is precipitated onto the working floor.

Of equal importance is the provision of a mechanical lock or latch to keep the ladle in an upright position during transportation. One of the most serious and appalling hot metal accidents of recent years occurred because of this very failure. Five lives were consumed in the twinkling on an eye when a ladle of hot metal tilted and poured its contents onto the floor.

Ladle trunnions should also be subjected to the most rigid inspection and at least once a week be cleansed with kerosene and wiped dry so that the inspector may be able to see the beginning of any progressive fractures in the metal. It is a good plan also, after the trunnion has been wiped dry, to paint it with thin whiting which will more readily disclose any surface cracks which may otherwise be quite imperceptible.

Moist pouring floors and damp floors under cupolas should also be eliminated and all iron carriers instructed against dumping drops in damp places. The slightest metal blow may mean the loss of an eye or weeks of suffering and time loss to the unfortunate victim. Close supervision on the part of the foremen should practically eliminate this cause of burns.

Protective Clothing

While proper engineering revision, inspection, education and supervision will largely eliminate the cause of foundry burns, someone has very aptly stated that regardless of what we do the foundry will never be quite as safe as a parlor. And for this reason, while considering the item of foundry burns and the elimination of many of the basic causes, we should go further and provide protective wearing apparel against the ever present possibility of burns.

Many reasons may be advanced against the use on the foundry floor of molders' shoes, leggings, goggles, etc., but I am inclined to believe that the arguments set forth are mostly excuses and the fact remains that in those foundries which are doing the most to prevent accidents and are meeting with the greatest success, the requirement of the use of protective clothing is almost universal.

A much mooted question is whether or not the company should furnish such protective devices free of charge. We are strong in the belief that with the possible exception of shoes, all such articles should be supplied free of charge by the company. When such is done, there can be but little argument against the use of such devices and I can cite no better example of the efficacy of such a policy than an eye protection record at one of our plants employing approximately four thousand men who worked for more than five years without the loss of an eye. Such a record was only accomplished because it was obligatory upon all men being subjected to eye hazards to wear goggles. On but comparatively few occasions did anyone claim that he could not do the job while wearing goggles and when it was courteously explained that he could not do the job without goggles, very few men automatically discharged themselves.

On some few items such as leather arm protectors, spats, etc., which make ideal blow-out patches for automobile tire casings, and goggles which are so much in demand by motorcycle riders, we have found it to be advantageous to have the men sign a wage deduction slip to the amount of the loaned article which will be used only in the event of misplacement of the device.

Handling Materials

While the hazard of materials handling in the foundry produces a slightly less accident frequency rate than burns, according to the U. S. Bureau of Labor statistics, foundry deaths and major mutilations are mostly caused by the transporting of materials. This is readily understood when we consider the severity of accidents attributable to the failure of crane chains and slings, magnets, chain blocks, insecure piling, etc. Such hazards may only be remedied by the closest supervision on the part of the foremen. While it may be perfectly safe to hook the crane chains to the heads or risers of steel castings for removal from the molds, the same would not be considered a safe practice in the grey iron foundry where a secure fastening should be made to the body of the casting.

Good housekeeping is again of major importance in the handling of material which not only greatly reduces the chances for injury but also expedites the operation. Where flasks are piled neatly and substantially and assorted as to size the likelihood of an accident in extricating the size wanted is greatly diminished. Stock piles of stone, pig iron, casting, etc., placed on level and substantial foundations also greatly reduce the chances for broken and mashed fingers and toes so prevalent in the long list of foundry accidents.

Perhaps the greatest strides made in recent years in the safe handling of materials are in the development of the numerous mechanical devices for this purpose. Just as the magnet handling pig iron and scrap has been the means of saving unnumbered fingers and toes from serious injury, so is the mechanical conveyor greatly reducing the hazard of material handling. As a general principle, a practical labor-saving device is also an accident eliminating device, and this latter factor should receive the

utmost attention when foundry executives are considering the installation of such machinery.

Other Non-Mechanical Accident Causes

Next in frequency following burns and material handling accidents come falling bodies, falls of workers and eye injuries. Of all types of accidents, the dropping of a piece of pig iron from a charging floor or a monkey wrench from an overhead crane onto the unsuspecting victim on the floor below, is the most regrettable. In practically all such cases, a fellow workman is to blame and nothing but the most effective sort of safety education will put a stop to such occurrences. When the organization is imbued with the spirit of fellowship to the point where individuals recognize their obligation to their fellow workmen, safety will progress by leaps and bounds.

This spirit was typified in a steel plant I know of where approximately 900 men went 45 days without a single man losing a single turn as the result of an accident. At the banquet celebrating the occasion, a stalwart mechanic gave as the reason for their success the slogan that, "We watch ourselves and one another all the time." That is the spirit that will positively prevent accidents.

The falls of workers may be more influenced by plant housekeeping than anything else, although proper daylight and artificial illumination are very important factors. Slippery walking surfaces also contribute to this accident cause and while floors and walkways should be smooth and free from tripping hazards, the surface should be sufficiently abrasive to provide ample shoe friction. This is especially necessary where men carry hot metal as well as around woodworking machinery where a fall may result very seriously.

Eye Hazards

Eye injuries in the foundry and other divisions of the iron and steel industry have received a great deal of attention from safety engineers, and rightfully so. Whereas the designer of artificial hands, arms, and legs has been able to develop a substitute that will do almost anything the human member can do,

no one has yet been able to produce an artificial eye that can see. For this very fact the eye hazard is the most serious of all non-fatal accident hazards. Even though we cast aside all social and humanitarian considerations and look at the problem purely from the economical point of view, the eye hazard still ranks second only to death in seriousness.

As in so many other accident causes the foundry again, but for one other division of the iron and steel industry, tops the list. In the foundry the ratio of eye accidents to all accidents is 14.4 per cent while the entire industry has a ratio of 9.5 per cent.

Generally speaking, the use of goggles should be compulsory for tappers at cupolas, molders when handling molten metal, sand blasters, chippers, and grinders. Where excessive heat is encountered in which it is next to impossible to keep the lens from fogging, it has been found practicable to substitute masks which may be tilted onto the top of the head when not needed in the protective position.

Sand blasters of course require a special helmet with a respirator for removal of the fine dust particles and provision for a fresh air supply.

Next to hot metal the greatest eye hazard is encountered in the chipping department where the air hammer is found in use in practically all foundries. While the liberal use of screens minimizes the danger of injury from the chips from the tools of other workmen, this protection is only supplementary and should under no consideration displace the safety goggle.

Abrasive wheels also offer a distinct eye hazard and the danger can best be guarded against by the use of goggles, which should be so designed as to exclude from the eyes the finest particles of emery, carborundum or whatever the composition of the stone may be. Being dust proof such goggles will also ward off the hot, sharp particles from the metallic surface which is being ground. In addition the lens of the goggles should be of sufficient strength to offer great resistance to flying parts of the abrasive wheel in case an explosion occurs while the wheel is revolving at high speed.

Many other eye hazards might be mentioned as well as many additional special hazards of foundry operation, but time does not permit of further discussion.

Suffice it to say that we foundrymen have our job cut out for us. As an important division of the great iron and steel industry we can scarcely be proud of our place in the procession although the dangers incident to foundry work are for the most part well known and the remedies are as obvious.

As leaders of safety thought in our organizations we must sense that the greatest danger of danger is indifference to it and devise and execute our methods of safety education accordingly.

What the Foundry Offers a Technical Graduate as Viewed by a Graduate Apprentice

By R. R. Meigs, Lynn, Mass.

This paper has been written with the intention of indicating some of the foundry impressions formed by a graduate of a technical college during a training period in a large steel foundry. The short-comings and limitations of such a paper are at once evident. It is difficult to describe the tangible results of an intensive training course and venturesome to attempt an evaluation. The diversity existing in foundries and the disparity in college graduates entering the foundry industry combine to make generalizations rather approximate. Under such conditions it is assumed that the inferences of a particular foundry student may be of interest in a general discussion of foundry student training.

Interests Formed During College Years

There are relatively very few men entering college with a definite idea of the work they will attempt upon their graduation. In a technical college, the undergraduates naturally tend to become interested in the various industrial fields. In most cases those branches of industry particularly attractive or interesting to the undergraduate frame of mind are chosen. These selections are usually influenced by what may be called the general conceptions of the possibilities for advancement within the different fields. Working conditions, preliminary training requirements, financial returns and so on are other deciding factors.

Some industries are well advertised in more than a commercial sense; they are known to offer definite opportunities in their special fields. Others possess an over-all unattractiveness, equally well known, but which is often more or less superficial or assumed. The undergraduate has no basis of real meaning or value to use

in comparing the openings available. In most cases he does not possess a fair understanding of the actual conditions or opportunities offered him in his final selection.

In late years some of the large manufacturing companies have sent their representatives to various colleges to speak before the members of the graduating classes and to describe the training and the positions available within these organizations. These informal talks are of considerable interest and actual assistance to the student in determining his first move. Their continuation and increasing scope seem to indicate that such a policy has proven effective from the employer's point of view.

Foundries Present No Organized Appeal to Graduates

Among the industrial divisions employing technically trained men it can not be said that the foundry industry affords a special incentive for the undergraduate to prepare himself for a start in that direction. The need of technically trained executives is frequently described in the columns of the associated trade-journals and in the proceedings of the related associations. The validity of these statements is seldom found questioned. Outside of these sources, however, there is little publicity attending the opportunities available for college trained men within the foundry. Undergraduates who are unfamiliar with recent developments in the industry possess an out-of-date conception of conditions within it. They turn, almost involuntarily, to other fields of endeavor.

If an accelerated influx of college trained men is desirable in the foundry industry, an organized publicity program would tend to bring it about. College classes would readily serve as agencies through which necessary contacts could be made. The fact that there is an ever increasing application of engineering practices to all phases of foundry procedure will in itself attract some graduates who may chance to be acquainted with particular instances. The majority of the average graduating class, however, need to be told what an interesting place an up-to-date progressive foundry can be.

Engineering colleges and schools as a rule offer a course in foundry practice. Some of these are naturally more comprehensive than others. These courses at the best can only serve to

familiarize the student with the major foundry operations, the working tools, shop terms and the like. They can not reproduce in themselves all the requisites or the organization existing in a commercial shop but up to a certain point they can be of real benefit. The serviceability of these courses is greatly increased by incorporating a number of inspection trips through the more progressive foundries of the locality. Another interesting feature is a series of lectures or talks given by foundry executives upon subjects pertinent in the development of foundry operation and technic.

Definite Schedule of Training Needed

Let it be assumed that a graduate of a technical college enters the employ of a foundry organization and it is agreed that he shall spend a certain period of time in training. It seems advisable that a definite schedule should be drawn up outlining the student's progress through the various departments of the shop. Such an arrangement insures the student of an all-around experience and eliminates confusion and delay in shifting from one department to another. The writer spent two years working in practically every department of a large steel foundry under the direct supervision of his shop superintendent.

The only worth-while way for a foundry student to break into the work before him is to start as a helper of some sort. The first problem which confronts him is that of getting into personal contact with the particular group of workmen with whom he is to work. The success of the whole venture, in some cases, is affected by the outcome of these first encounters. With some groups the task is a delicate one; the least over-reaching and the green hand is in difficulty. In other groups, there is a cordial atmosphere from the first and breaking in becomes a new and interesting experience.

Student Should Adapt Himself to Shop Customs

Not until a sound personal contact is made can the student hope to obtain any amount of real first-hand information. Only when he has become a full-fledged member of the group will he have their confidence and good will. The ordinary workman is willing generally to become an instructor provided the student

will adapt himself to the teacher's method. The actual process of adjustment is influenced by a number of factors governed by the individual shop organization and personnel. To obtain the maximum benefit from his training the student should accustom himself to conforming with established customs as he finds them.

When the student succeeds in acquiring an acceptable background, the really profitable part of his apprenticeship begins. His workmen friends will commence to talk shop with him. Most of them have interesting stories of their personal experiences in earlier days and in other shops. The helper status will gradually be transformed until he is generally described to newcomers as, "a young fellow picking up the business." In the writer's opinion this is the ideal attitude. Under such conditions the student may be allowed really to assist an old-timer draw a pattern or cut a gate. The significance of such achievement is not in the student's acquired skill but lies in the fact that the student has been accepted as an associate by a workman and in a normal, natural manner.

A foundry student may be given a job of his own at the very start and given special instruction but such an arrangement is apt to work hardships and become unpleasant. It prevents the student from catching the shop morale and from getting an idea of the viewpoint possessed by workmen in general. By working with a man and coming to share in an impersonal way his tasks and duties it is possible to get an insight into his thoughts and problems. It gives one an opportunity to size up the industry from the standpoint of those who work for a daily wage. The student with a little effort can get their notions of matters pertaining to management, industrial development and working conditions. He can learn to discriminate between a good workman and one who is inefficient. This sort of experience and its attendant information is invaluable to a college graduate, and in general, is more difficult to obtain and appreciate than a working knowledge of foundry practice.

Management Should Keep in Touch With Apprentices

While a student is serving his time on the floor there are times when the novelty of the situation wears away. Routine with hard work is apt to become monotonous. The biggest stay on

such occasions is an interested member of the management who keeps in more or less direct touch with the student. A conversation relating to shop problems or proposed improvements will give the beginner something to think about other than the weight of a shovel of sand. Such discussions provide the student with an outlet for any ideas or information he may have acquired. They also give him an opportunity to straighten out any possible misinformation.

From the foundry student's point of view there are three general classes into which foundries can be divided. The first group contains those foundries which are wholly modernized. A large portion of these are production shops with specialized equipment and elaborate labor saving devices. The second class includes those shops which may be described as being in a transitional condition. In these foundries old rigging and methods are being gradually replaced by new equipment and improved methods as these developments prove themselves to be truly practical and economical. The third division embraces the remainder, or the shops which are backward in accepting the results of recent industrial progress.

Shops Which Are in Process of Improving Offer Advantages

To the writer's mind, a foundry in the second grouping mentioned can offer the best facilitations as a training place for a prospective foundryman. In this type of shop there is enough of the earlier day practices discernible to enable the student to visualize somewhat the conditions existing in those days. The subsequent developments can sometimes be traced by examinations of discarded equipment laying in the scrap-pile.

In the personnel of the organization there are bound to be men who have had a great amount of practical experience in a wide variety of lines. When new equipment or methods are being considered, these men through their criticisms are valuable sources of information. Personal prejudices often turn out with considerable solid foundation. In such an atmosphere, provided, of course, that he is permitted to enjoy it, a student can pick up a fund of general foundry information outside of that obtainable from his own observations and experiences. This advantage be-

comes more apparent in cases where the shop does more or less jobbing and includes work of different types.

Thus the characteristics of the various groups determine the scope and nature of the training available. The fundamental ideas and impressions which a student acquires of the industry as a whole are dependent upon the same factors. A training complete in one particular class is not very comprehensive. In order to obtain a general conception of the industry it is desirable that a training course include a number of inspection trips through outside foundries of different types. These visits do more than increase the foundry student's information; they assist him in classifying and appraising that which he may already possess.

What May Be Expected to Result From Training Course

Just what may be expected to result from a training course is a matter which perhaps is of more actual concern to the student than to anyone else interested. The time involved, in addition to the four years spent in college represents quite an outlay. The factor of first importance in the final result and one which depends largely upon the student himself, is the extent to which he has fitted or adapted himself to foundry requirements. It might be put as, the extent to which he has been adopted by those responsible for these requirements.

After spending some time in a foundry a student ought to arrive at some conclusions regarding his chances of making good. If he elects to stay he should select some phase of the work which interests him particularly as a specialty. The type of college training he received may have considerable bearing on his choice. He may become interested in the metallurgical operations, or in costs and production, or in the managerial side of things. There is the field of research for those who are inclined to the scientific or theoretical. The work of a consulting foundry engineer may interest another. The actual information or technic obtained through an intensive training is apt to be discounted because of the lack of experience behind it. The effects of a technical or college training must be tempered by a foundry-sense which may be said to prevail among all good foundrymen. Under such conditions, the earlier the foundry-student succeeds in establishing a

definite goal, or line of attack, the more effectiveness he can command at the completion of his training.

A relatively small amount of actual foundry experience is possible in one or two years of training. Thus it is only when a reasonable result is expected and due allowances are made on both sides, that a foundry training will turn out with satisfaction to all parties. A college trained man should be able to assimilate detail and routine more rapidly in essence than an untrained man. A technical education supplies a special kit of working tools and some insight into the facts is back of many rules-of-thumb. After a period of training, say two years, the average graduate under interested supervision should be fitted to assume a position carrying a portion of responsibility. The exact position wherein he can be of most real service depends upon the individual foundry, its personnel and its problems.

The foundry industry is said to be in a stage of constant development. This progress may be said to consist largely in the evolution of mechanical equivalents for manual labor, the elimination of waste and the improvement of the final product. Such a development creates a proportional need for technical knowledge and should automatically increase the foundry demand for technically trained young men. At present, when foundry expansion is becoming so rapid and is breaking so sharply away from the past, a lack of contact with earlier practices cannot be held as a complete or extremely serious disqualification. Practical experience, with its beneficial information, is of prime importance, but it is something accumulated through years and no training course can provide a short-cut. The obligation of a student in a foundry is to fit himself to carry on the work of foundry development from the point where those before him have brought it. To do this it is necessary that he become acquainted with certain well established principles which the past has proven inviolable. After this step, under favorable conditions, he should go on acquiring experience and knowledge from his own efforts and the developments of his time.

Apprentice Training

The session scheduled for discussion of the topic Apprentice Training included in the program of the Syracuse meeting, will consist of a discussion of questions secured from foundry managers who are interested in this phase of foundry management.

The questions which are listed in this pamphlet are such that a full discussion of them should prove of great value to any who are undertaking apprenticeship training or who contemplate such training. Written discussion of these questions can be mailed to the secretary of the association or read at the meeting. Other questions which members may desire to have discussed can be handed to the chairman of the convention session or put from the convention floor.

Questions for Discussion

1. In shops that support no definite apprenticeship program what is the chief objection to systematizing trade training and adopting a clear cut apprenticeship program? Are the objections raised as follows:

a. Difficulty in keeping boys interested in their work after the first novelty wears off.

b. Difficulty in providing a complete apprentice program in a small or specialized shop.

c. Difficulty in providing instructors in related subjects which are necessary.

d. Difficulty in developing in the apprentices a spirit of morale and loyalty.

2. What is a district apprentice program?

3. Is a district apprentice program suitable for small community needs?

4. How large a community does it take to effectively organize a district training program?

5. How can a state vocational training director help your community organize an effective training program?

6. What can be done to interest the foundrymen of your district in organizing a cooperative plan?

7. Should the manufacturers cooperate with the schools to undertake continuation work of a general nature, or should the continuation work be of a trade preparatory type?

8. Is a community or district apprentice plan advisable?

9. What plans are advisable for each foundry to contribute its share in the training program of a district?

10. Is there a uniform course of shop instruction for apprentices agreed upon among employers in your locality? If there is, how was that brought about?

11. Other things being equal, can a graduate apprentice from one shop hold his own as a journeyman in another shop with a fair degree of success?

12. What has been done in the way of a survey in your community in order to ascertain how many journeymen must be replaced by younger men each year? That is, how many apprentices can the industry absorb?

13. Are there any prearranged plans among the employers designed to keep apprentices steadily employed? For instance, if an employer is temporarily low on work will other employers consent to take his apprentices for the time being?

14. Has a standard or uniform wage scale been agreed upon? If so, what approximate ratio is it to that of the journeyman's?

15. To what extent do the local employers cooperate with the journeymen?

16. What provisions are there for furnishing apprentices with the necessary related trade information?

17. In what way is the apprenticeship program linked with the public schools, such as the continuation or vocational schools,

university extension division, correspondence schools, and technical schools?

18. What activities are being carried on to make apprentices better citizens as well as better mechanics? Are apprentices brought together for social or educational purposes?

19. Are apprentices placed under indenture? What arguments are there for and against that procedure?

20. Is there any attempt to maintain a certain ratio of apprentices to the number of journeymen?

21. In such shops as have had an apprenticeship plan for some years what percentage of those apprentices taken on have completed their training?

22. What was the approximate cost per apprentice graduated?

23. In shops that support no definite apprenticeship program what is the chief objection to systematizing trade training and to adopting a clear-cut apprenticeship program?

24. Considering the two classes of shops—those that have an apprenticeship program and those that do not—how does the cost of labor turnover compare between the two?

25. What inducements are held out to prospective apprentices?

26. Is there any one man in the individual shops who is held responsible for the success or failure of the apprenticeship program in those shops? If there is what are his duties in a general way? Does he do the hiring of apprentices, etc.?

27. What methods are used in recruiting apprentices?

29. Are the foremen as a whole sympathetic with whatever apprenticeship plan is in force? How are they sold the idea?

30. Is there a live apprenticeship committee in your community?

31. What is being done to bring such employers into line who make it a practice to rely on others to furnish them their trained men?

Discussion—Apprentice Training

CHAIRMAN C. B. CONNELLEY: To us, there is nothing quite so vital in the foundry industry as the human element in the apprenticeship system which we are trying to establish in the United States and Canada. We are greatly indebted to Mr. Meigs for his excellent paper, and I hope the college men and the educators who are at this meeting will give us their experiences in this matter.

Never, in the history of America, has so much attention been paid to the training of apprentices, so much money expended, or so much energy spent as now. In Pittsburgh, we have a cooperative plan whereby organized labor and the manufacturers in the building trades work together, and, with the assistance of the board of public education, give boys and young men special instructions in their own trades. We all benefit by this arrangement, and it will mean much in the future. I feel that with the help of the American Foundrymen's Association, the National Founders' Association and the various school systems throughout the country, we should be able to get good results with our apprenticeship program.

I shall now call on E. A. Johnston of Wentworth Institute to tell us what his institution is doing in a practical way, not only for the semi-engineer, but for the apprentice in Boston.

E. A. JOHNSON: The work at Wentworth Institute, having gone on for about fifteen years, is the outcome or development of work we had carried out at Indianapolis previous to that time. We found by experience that the training that was needed for the young man who was to go into foundries was a course of instruction that would start with the practical end. It was known in those days that the industry was changing from rule of thumb methods to more scientific ways of controlling the product and the method of producing the product. So we built to make the course practical. We have found by experience that it requires practically 50 per cent of the school term to apply to the practical phases of training. That training must be brought to the student in exactly the same way as though he were in a shop and that training must also be brought to that student by some one who has had practical experience.

The student at the beginning must be given fundamental principles. To this must be added skill and speed. He must be brought just as close as is possible to a commercial speed and just as close as possible to commercial skill. I say "as possible"; I mean by that as close as is possible in the time given for that sort of work.

I have found by my experience this can be done in two years. In addition to that, in two years it is possible to give to young men the technical phases of work that he is going to require as a foundation. This becomes necessary because any young man who goes into this or any other industry does so to prepare a future for himself. The industry requires this sort of training, as it is tending more and more in that direction.

We teach chemistry in our department, not in the sense of making chemists out of those boys but because chemistry plays a very important part in the control of the production of casting. We teach them technical analysis in the second year, since that acquaints them with what the analysis really means.

The way we coordinate these two things up is by taking these chemical analyses that the boys make in the laboratory and use them in the shop.

We build machinery, we make a high grade lathe and various other articles and they are first class. They are used by manufacturers all through our section of the country. We don't do this to compete in a commercial way, we do it to provide a standard for those boys to work to. That must necessarily be as high as the best commercial standard. The material in these castings must be of a grade equal to a commercial standard, both in quality of finish as well as the grade of material. We teach those boys what mixtures really are, how they are affected by the elements contained in the metals and we use a chemical laboratory for that purpose only. If there are any defects or problems to solve, the boys work them out, sometimes with our assistance, sometimes by themselves.

We also include in the course, in the second year, a training that we believe develops their initiative, resourcefulness and ability to assume a certain amount of responsibility. We place a certain amount of trust upon these young fellows by having them organize as a commercial shop. Under this organization we have a foundry superintendent, a foundry foreman and his assistants and a group of workmen. The foundry superintendent is a second year man. He is made responsible for production, and enters all the orders that come into that foundry, and sees that deliveries are made on those orders. He must determine what sort of metal is going into those orders and he must see to it that it is right. If any defective castings come out, he must determine why they are defective and find a remedy for the next batch of castings that come out. He must see that the inspection is rigid enough that the standard is kept up. We rotate the boys in these positions so each boy gets an opportunity to work in each position. We find at the end of that year they have developed a whole lot of talent in these positions.

We talk to our boys all through the two years of the possibilities in the field and yet warn them against having their hopes too high as to the time when they are going to become foremen or superintendents. Rather, we like to see them go in as helpers—then advance from helpers to molders. We find by experience those boys go out of the ranks and become men who are given a little responsibility. We don't really like to see that happen too soon after they get into the plant. We like to see them work through three or four years before they are pushed ahead that far and yet, rather strange to say, it does happen sometimes.

The big problem now is not the teaching or the way of doing it. The big problem is getting young men interested in taking the work. That

will become an easy proposition if the young men know there is a demand for their services. If the young man can be made to feel that there is some future prospect in store for him, if foundrymen will accept these boys in their shops, demand young men with training of this sort and give them a fair chance to prove in their shops what they can do, if the foundrymen will watch those boys and permit them to grow, it will create a natural demand for such trained boys. Then you will have plenty of material from the high schools, plenty of boys who will become interested in the business and there will be no trouble at all in furnishing all the likely young men that you will need in your plant for the future.

CHAIRMAN CONNELLEY: The citizens of a community have the right to demand that their board of public education provide means for the training of young men in the industry. This should be begun in the grammar schools, and vocational counsellors should be appointed who will take an interest in the boys.

It is appalling to see how many of the children who enter schools drop out before they reach the eighth grade; and still more appalling to see how many do not finish high school. We will, of course, always have students in high schools, but it is up to those in the technical field to take care of the industries. Our work is to interest the parents in the education of their sons They want their sons to have a better chance than the father had.

We have already heard about Wentworth; I shall now ask Mr. Ramp of the Newport News Shipbuilding and Dry Docks Company to tell us what they are doing.

P. R. RAMP: I want to tell you what we did in Newport News. In our foundry we have twenty-two apprentices on pattern making and we have twenty pattern makers. We have twenty-four apprentices in the foundry and sixty molders, at least, that is what they call themselves. In the steel foundry we have ten apprentices molding.

About one year ago, we had four apprentices in the foundry. All they were doing was helping the molders and they made poor helpers, at that, the poorest four we have right now, but one of them wanted a raise the other day.

We had until four months ago, ten apprentices in the pattern shop. We had an apprentice system that worked well in the machine shop but it was never worth a cent in the foundry.

My foreman started in with the idea those boys were no good. After I got to figuring the thing out, I found the foreman was no good. I found we were training the wrong gang. We want to train the foreman, and that is what I am doing. If you think your apprentice is being given the proper instruction, call in your foreman and hand him a difficult pattern and ask him if he thinks a certain young boy can make that, and you will get fourteen hundred alibis why he can't make it. With a condition like that, you have the wrong man on the job.

I have the best boy on No. 1 Bench, the next best on Bench No. 2, and so on, and we create in them a competitive feeling. Today every apprentice in the foundry is working by himself and trying to do a day's work, for I go around amongst them myself. I don't trust the foremen because I do not think they take it as seriously as I want them to.

Today, every apprentice in the pattern shop is working alone and making good patterns. Recently they have all been working on manifolds. We have four boys who have been there three months making the nicest looking manifolds that you would want to look at. I had one fellow make one pattern over three times and still come out ahead of the estimated time the journeyman took.

Today we are getting less scrap. We are getting less scrap out of the apprentice boy than we are out of the molder. There are some exceptions, of course, to that. In our foundry we have a deadhouse, a morgue for the scrap, and each boy has to explain his defective work. The fewer pieces they have, the harder we ride them. You would be surprised how they hate to go in the deadhouse. I remember I said to one boy, "You have worked here four months at molding and look at that thing."

He said, "It is the first time I have ever come to confession, though."

When one boy starts down to the deadhouse, you should hear the rest yell to him.

Our work is ship work and runs from a half ton to sixty tons. We don't make quite as many half tons as we would like. We work the boys once in a while with a man, but we are sure to pick the man. I think we have been successful in developing these men in so short a time, ten months.

The secret of our success has been teaching them ourselves. That is what I want to tell you about. I have a large lecture room and every Wednesday afternoon I give them a lecture. Maybe today we find they are ramming too hard. Then we give them a lesson on ramming. We write a standard for all jobs, listing items even for such small things as putting a spike in a particular place. We have a cross section of the mold, a drawing of the mold as it is being rammed. Then we give a lecture on the job.

Sometimes in an apprentice system the apprentices are babied. Just as soon as you baby an apprentice, you get in trouble and sometimes the supervisor of apprentices is a little inclined to do that. Mr. Johnson said we should give them at least our moral support. We have to give them more than that. We have to take those boys and put them to work and make them tell what wonderful things they are doing. Don't keep them on the same job because they are doing it well. Our shop is a jobbing shop. Any shop of that kind gives plenty of opportunity and it isn't long before they are telling you why they are doing things.

CHAIRMAN CONNELLEY: Mr. Ramp spoke of the particular training which apprentices receive in Newport News and which might not be

adaptable to other sections of the country. He is right in that; it is a fact that the human factor must be brought into practice. It was the human side of the industries that first introduced the "safety first" movement, which has been so very successful. The safety congress was first organized in Milwaukee in 1911. Since then, industrial accidents have been lessened to a considerable degree. A number of years ago, in Pittsburgh, during the construction of a twenty-four story building, one man was killed for each story up to the seventeenth.

About two years ago I had the great pleasure of meeting a man who is spending considerable time and energy in the advancement of the ideals of the human factor in the foundry. He is associated with the National Founders Association, and works in cooperation with the National Association of Manufacturers. I am going to ask Mr. Hartley to talk to us about what he has accomplished in this field.

L. A. HARTLEY: There are three factors in industry: Materials, equipment, and man, and the greatest of these is man. I want for a moment, if I may, to call your attention to the fact that materials have been developed perhaps 90 per cent as far as they ever will be developed in the history of the world. We have another ten per cent to go on, perhaps.

I believe also equipment has finally been passed on by the owner, passed on by the employer to the manufacturer and today we find ourselves continually being requested by salesmen and experts and service men from manufacturers to try out a new piece of equipment. No doubt you have seen many pieces of equipment in this exhibit which you believe not yet to be quite practical. It means an effort upon the part of the equipment manufacturer to deliver to your continually something a little better in that branch of your needs.

But the main factor, that third factor, is the only factor that we have not consciously tried to develop. There is no limit to the possibility of a human mind.

I sometimes think of the best job I have ever seen in this country anywhere that a manufacturer has done. It is at the Ohio Brass Company's plant, the plant of L. W. Olson, retiring president of the American Foundrymen's Association. I want to tell you something of the work Olson is doing. I have known of the increase of production in that plant without one single iota of new equipment, not one bit of new equipment. not one more additional man power and yet, an increase of production of one-third. Isn't that remarkable? Isn't that worth considering? All in the world they have done there is merely to make every man in that plant feel that the plant is his friend. That is simple, isn't it? Every man in that plant feels that he has a friend in the Ohio Brass Company and that the Ohio Brass Company will stand behind him and see that he gets justice with the shyster lawyer, see that he gets justice with the man who has a mortgage on his home when he has difficulty. I have gone

out into the plant and I have seen the faces of the men, working as hard as they possibly could, but happy.

I think in the end sentiment does more to move the world than all the planning we might do. Psychologists tell us there is a state of mind they call the abulia. It is the chasm that exists in some men's minds between planning and action and there are a lot of people with a lot of abulia. I sometimes wonder if we can't plan more definitely, more specifically to do some of the things we talk about. I sometimes wonder if we cannot step over beyond the chasm.

CHAIRMAN CONNELLEY: I have before me a letter from a Milwaukee firm apprenticeship supervisor. It is a little too long to read here. So many of our institutions in the United States talk a lot about what they can do for the apprentice, but Milwaukee is the only one which has actually shown wonderful results, and has done very little talking. This city has worked not only with the foundry trades, but with all machine trades.

The boards of education of the different cities can be of great assistance. In Pittsburgh, this board provides a fund of $100,000 to be used to teach boys and young men a trade. It works in cooperation with the employer and the boy. An example of this is our plumbing school. The boys go to school one-half or a full day a week and are paid for the time they spend attending classes. The authorities are very strict, and by means of a card system a check is made on the number of times a boy is absent. At intervals an inspector or investigator visits the school and reports the progress to an industrial commission, which is composed of men connected with the plumbing industry. The master plumbers not only pay the boys, but they pay the city a school tax. If this is the case, why can't each city provide a school similar to the one we have in Pittsburgh?

Question No. 5, of the paper you have, reads, "How can a state vocational training director help your community organize an effective training program?"

If there is a vocational director in your community, and you feel that your progress is slow, write to J. C. Wright, the Director of the Federal Board of Vocational Education. He will see that matters are adjusted. You are paying for this service, and are entitled to get it.

M. J. LEFER: In Moline we have no vocational training school and so we finally decided we needed molders badly. We take a boy in and give him a lot of follow-up work, then piece-work and then he is a molder. We have eighty apprentices. We call them apprentices, but they are really not apprentices and we don't pretend they are. We think it is an excellent substitute for the vocation school for picking up prospective apprentices. Out of that sixty or eighty we are going to get a dozen that are first class. They make any job and they make from thirty to fifty dollars a week in a section where wages aren't quite so high as other places. We are just

going to start those dozen boys as Class A apprentices in a regular apprentice course. It is the best we can get hold of.

Don't you think that is as good a system as taking boys from vocational schools if you have no vocational schools to choose from?

L. A. HARTLEY: Mr. Chairman, there is one thing I wanted to say here and I have to say here because I don't want to be misunderstood. From my experience, as one who was receiving half my salary from the Federal Board for five years, I wish to say those who are thinking of placing their dependence on these vocational schools, don't do it. Do not make the capital mistake of placing your dependence upon any school system. The gentleman from Newport News is absolutely correct. You fellows must do this yourselves. You must undertake this work and see it through. If you want my exact understanding or the National Founders Association's exact understanding of this vocation school, you can get it from my address before the U. S. Chamber of Commerce in Washington on May 20th last. That was published by the U. S. Chamber of Commerce and will be distributed to you upon resquest. We have two thousand copies for distribution and you will get it if you ask for it.

A. E. BARLOW: I want to echo the suggestion made by Mr. Hartley and others about the human element and tell perhaps, in a few words, what we have done at Newark. Trying to get back to what appears to us the first principle of making the foundry more popular, the responsibility rests entirely, I believe, or essentially primarily upon the foundry operators. They are the ones I think that are responsible for the unpopularity of the foundry business. You can analyze the situation, go as far as you like, and I believe you will find if there is any responsibility for the foundry business being unpopular, the foundry owners are responsible for it. If there are positions in the foundry that do not appeal to the boys we must correct them. If there are conditions which should be improved, which are not sanitary, we can make them better.

A man once said to me that I was practically a fool for saying we must popularize the foundry industry. I replied, till you do that you will never get new boys into your shops. I believe that is what we must do. Our enthusiasm must diffuse itself among the boys we try to interest. Now the boys we have in our schools must be interested. They can be interested through the vocational schools, the continuation schools, through the boys' work of the Kiwanis Club, the Rotary Club and other organizations with men that have an opportunity to talk to boys. There are many ways in which we can put life and spirit into this work. We felt that was so in Newark and we felt that we must have the co-operation of the vocational school, not that we must rely on it altogether, but it was a help. We insisted on the board of education furnishing a foundry course in the vocational school, which they did. They were not sure they were

going to have enough boys to make it worth while but they started with eighteen. They have nearly that number now on the second year. Some of the boys are interested enough to want a night course to supplement their practical work in the foundry and who went through it all last year.

The new courses have started again. That is a good sign that the boys are willing to spend two nights a week in learning more about their business and becoming more efficient. That comes because the men have interested themselves in those boys and told them how they could improve and what a future they might have. They have made the foundry business more than a dull, drab, dirty job that some men think it is. They have put vitality into it. You say that may be altogether impossible or perhaps visionary, but it is not so. We must put a whole lot into a business if we want that business to succeed.

A. E. HARRISON: Our friend stated that he heard or thought that the boys all came from the high schools. I want to correct that. We have fifty apprentices in the Allis-Chalmers foundry and none of them comes to us through the influence of the school. The way we get our boys is we send a man around to find them. He goes to their homes, talks to their parents and so forth. I just thought I would make that remark because it isn't necessary to bring them from the school That is very true, indeed. If in this work we can select a boy whom we think is going to do well, then it is our duty or the duty of the vocational counselor to tell you that the boy can do that. If we select the boys that are best fitted, we are going to be more happy and we need never worry about labor troubles or a revolution.

CHAIRMAN CONNELLEY: Immigration in the past provided us with skilled workmen at low cost, but when that was stopped we found ourselves at a loss and with no means of replacing these men. The school systems annually spend millions of dollars on the education of our boys and girls, but are only now beginning to appreciate the fact that apprentice training is necessary before we can have skilled workmen in our industries.

In this country, where every person has an equal chance, apprenticeship training has come to stay. It is just as vital to the commercial advancement of this country as the air which we breathe is to the body. I trust that before long not only Milwaukee and Boston and Pittsburgh and the other cities which have adopted apprentice training systems will be able to show results, but that this system will be practiced in every community in the United States.

Question 12 of the questionnaire asks: "What has been done in the way of a survey in your community in order to ascertain how many journeymen must be replaced by younger men each year? That is, how many apprentices can the industry absorb?"

First, survey your community; get the number of men employed and from that the number employed in the several industries. Each locality is governed by the conditions existing in it. Badly as they are needed, there will be few apprentices in an open shop town and still fewer in a closed shop town. You can get data on this through the Chamber of Commerce, the Manufacturers' club and the Board of Education. If it is not available, find out the reason why.

Report of Committee on Corrosion of Metals

To the Members of the American Foundrymen's Association:

Your Committee on the Corrosion of Metals, more particularly the individual members thereof—has, during the past year, kept in active touch with various phases of corrosion research in the United States.

As was stated in the committee report last year additional corrosion specimens will not be uncovered until next spring by the U. S. Bureau of Standards. Accordingly, a report on the specimens will not be available until some time in 1926. In the meantime, extensive laboratory experiments are being conducted at the bureau in Washington and it is hoped these will determine the factors, or at least isolate some factors, which cause the variations in soil corrosion. It is probable that within a year from this time there will be considerable data for consideration.

Work conducted by Committees A-5 and B-3, of the American Society for Testing Materials, together with work by their respective sub-committees gives promise of improving upon laboratory methods for making accelerated corrosion determinations, especially on some of the more newly developed metals. The large fund of scientific data that is being compiled by the above mentioned committees and others is helping greatly toward a clearer understanding of corrosion itself. While considerable time must necessarily be consumed in order to fully understand all contributing factors, it seems certain nevertheless that progress toward that end is being rapidly made.

Your committee has two representatives who are working on Committee B-3 of the A. S. T. M., it being known as a committee on the "Corrosion of Non-Ferrous Metals and Alloys." The first work attempted by this committee was to standardize the laboratory or short-time methods of making corrosion tests. Heretofore corrosion tests have been made by a multitude of investigators, each working by his own peculiar methods and in

the end very rarely did any two, even when working with the same materials, produce results which checked each other. The first work of Committee B-3 was undertaken to correct this situation. At present the committee is investigating with the view to standardization of the following four methods of determining the corrodibility of metals: (1) the total immersion test, (2) the alternate immersion test, (3) the spray test, and (4) the accelerated electrolytic test.

The metals and alloys used in tests were chosen to be representative of the non-ferrous field and are as follows: admiralty metal, aluminum, copper, lead, nickel and zinc.

The reagents used were also chosen to be representative of different types of chemical attack. They are: sodium chloride, hydrochloric acid, acetic acid, sodium hydroxide, ammonium hydroxide and postassium bichormate—all in normal strength solutions.

When this branch of the work of Committee B-3 is completed, it is sincerely hoped in all quarters that much of the confusion which now bewilders the investigator and retards progress in corrosion research will be cleared away so that future tests will yield more wide-spread usefulness than they have in the past.

In the meantime, your committee feels that investigators should not lose sight of the time honored method of going to the field and checking the corrosion resistance of metals by observing the respective behaviors of those metals under known practical service conditions. Of course, this method is subject to the objection that all of the contributing factors or phenomena are not known, and cannot accurately be determined, but on the other hand, the laboratory rarely if ever reproduces all factors that are found in the field.

Respectfully submitted:

GEORGE K. ELLIOTT,
KIRK H. LOGAN,
H. S. RAWDON,
WALTER WOOD,
H. Y. CARSON, *Chairman.*

Report of Committee on Heat-Treatment of Ferrous Castings

To the Members of the American Foundrymen's Association:

Your committee on the Heat-Treatment of Ferrous Castings reports that its work during the past year has been mainly confined to cooperation with committees of the A. S. T. M. dealing with heat-treatment of steel, malleable iron and gray iron castings. It will be remembered that the A. F. A. committee was organized according to the present plan, to maintain proper cooperation between the A. S. T. M. and the A. F. A. The A. F. A. Committee is divided into three sections and the arrangement is such that the chairman of each section is the A. F. A.'s official representative on the corresponding A. S. T. M. sub-committee of the testing society's general Committee A-4. The chairman of the A. F. A. Committee proper is the Association's representative on A. S. T. M. Committee A-4.

During the past year, Committee A-4, through a sub-committee, developed a recommended practice for the carburizing and heat-treatment of carburized objects. This recommended practice (A37-25T) was adopted as tentative by the testing society on June 25, 1925. When it is later made standard after satisfactory trial, it will supersede the recommended practice for the heat-treatment of case hardened carbon steel objects designated as A37-14.

At the last convention of the testing society there was no action taken to raise to a standard classification the recommended practice for the heat-treatment of carbon steel castings (A36-24T) tentatively adopted in 1924.

An important cooperative movement intended to result in universal acceptance of distinctive terms relating to heat-treatment operations has been inaugurated. The American Society for Testing Materials, the American Society for Steel Treating, and the Society of Automotive Engineers have formed a joint committee for this purpose. There have been important differ-

ences of opinion among engineers and metallurgists regarding the suitability of certain terms employed in heat-treatment operations, and it is hoped that the activities of the Joint Committee on Nomenclature will eliminate the present opportunities for misunderstandings of terms used in specifications for castings as well as for other metal products.

Your committee reported at the 1925 convention that there had been presented to A. S. T. M. Committee A-1 on Steel, recommendations to develop for use as standard, heat treatment procedures for alloy steel castings. No action has yet been taken in this matter.

Your committee will be glad to have suggestions and data relating to the activities of any of its sections. Members are cordially invited to keep this in mind and to address communications to the undersigned chairmen of the sections of the A. F. A Committee.

Respectfully submitted:

ENRIQUE TOUCEDA, *Chairman*
of Malleable Iron Section,

J. FLETCHER HARPER, *Chairman*
of Gray Iron Section,

R. A. BULL, *Chairman*
of Steel Section and of Main Committee.

Proceedings of Cost Session 29th Annual Meeting American Foundrymen's Association

The session was called to order by Chairman A. E. Hageboeck.

CHAIRMAN A. E. HAGEBOECK: There is one thing that should be called to the attention of the foundryman, that is, he should know his costs. I think that a lengthy discussion here is not necessary, we just want to bring out four facts:

First: We recognize that many failures (we have had lots of them) have been due to the fact that the foundryman did not know his costs.

Second: Castings should be sold on a basis of the cost of production.

Third: A correct cost-finding method is essential.

Fourth: A uniform method of determining costs is certainly highly desirable.

I was eating lunch today with some foundrymen and they did not know I was particularly interested in costs. The conversation drifted along and one fellow who happened to be from Chicago, said, "You know the main trouble in this country is that the foundrymen do not know what their castings cost them." I said, "Are you going to the cost meeting?" He said, "No." "Why not? Why aren't you going?" Well, he didn't know

That illustrates our experience in our locality. We could not get the foundrymen interested. I have attended lots of cost sessions at the American Foundrymen's Association meetings and I will say that up till last year, when Mr. Corbett's paper was read, there was very little interest.

This attendance here today shows that there is some interest and our committee especially wants to invite you to look at our

cost committee booth in the registration building. Some of you probably have visited it; if you have not, I want to call your attention to four castings on which prices were obtained in the regular way. The people who submitted the prices had no advance information, knew nothing about our plan at all; they just believed they were bidding on a job, that somebody wanted. For a light hardware casting, weighing 4¼ pounds, the spread is from five cents to twelve cents. Certainly we need some uniformity.

Bids on a steel casting made by the electric steel process range from nine cents to fifteen cents and it was interesting to note that in those prices there were four bids that were within half a cent. These four bids ranged 12, 12.4, and 12.5 cents. Those four foundries were all figuring by the same method. On a jobbing casting weighing 750 pounds, prices were asked for on lots of one and lots of ten. Most of the replies came in within a quarter of a cent a pound variation between making one casting and making ten. You all know that if you make one and lose one, you have got 100 per cent loss and your chances of coming out are pretty slim. Those prices range from three and three and a quarter cents to ten cents a pound.

On an automobile transmission case casting the bids ranged from $4.50 to $6.50 and those bids were taken in on lots of 5,000 about three months ago. This last example was not the result of the commitee's work; it was actual performance. Think of it, a difference of $2.00 on the same casting.

In order to not have this meeting too dry, we are going to start out with a twenty minute talk—I wish I could give more time—by a gentleman representing a company which has taken an unusual interest in the foundry industry, the Metropolitan Life Insurance Company. I understand that this gentleman who is going to speak to us has visited a large number of foundries and investigated the foundry management and is looking at the foundry, if you please, from the outside viewpoint. I take great pleasure in introducing Mr. W. J. Barrett, of New York City

Foundry Management and Its Effect on Foundry Costs

By William J. Barrett, New York*

Mr. Chairman and gentlemen of the foundry industry: Foundry management is an all inclusive subject and covers a wide range. This afternoon I am only going to give you a few of the pictures I have seen in the course of a rather intensive investigation which took in a number of representative plants in the industry throughout this country.

Measuring Management

Of late there have been numerous efforts to arrive at some measure or yardstick for judging management. That is, some formula, which used as a yardstick, could be placed alongside of your plant and from its indication would give you a measure of what your management was accomplishing. Up to the present, results in this direction have been but indications. We have no absolute formula that we may use, principally because conditions in individual plants vary so much. However, I do believe there are certain reflections of management by which we may measure management policies.

Labor Is Vital Factor

Labor is the principal factor in the foundry and anything affecting labor may be directly reflected in the results of management. Recently it has been said that 168 tons of material are handled in the foundry to produce one ton of castings. It is reasonable to assume that the management policies regarding the handling of this material affect the foundry employees, particularly those performing the laboring work in the foundry.

Iron and Steel Foundries Contrasted

In general, iron and steel foundries differ mainly in their methods of material handling. The one uses a good deal of main strength, while the other uses modern machines for handling material. Tons of material moved daily by machinery in the one

*Metropolitan Life Insurance Co.

plant, and by man power in others. Now it seems logical to assume that a reflection of the respective policies in these two industries would be the ultimate physical effect on the workers. Perhaps the records of a company like our own, insuring great masses of workers, might present some interesting facts in this connection.

As a matter of interest, I asked our actuaries to give me some picture of our experience with workers in iron and steel foundries. We have a certain number of plants insured under our group insurance plan. The number is increasing year by year. The experience set is, therefore, gained from varying groups and cannot be set down as absolute. However, it is interesting.

I think that a little explanation will be necessary to make clear the actuarial terms used. Each year, or at the beginning of each fiscal period, the actuary estimates what we may expect as to the number of people who will die in a given group. This figure is determined by the experience tables and data collected from similar risks and people working under similar conditions. The actuary sets up what might be called a budget figure for the number of people who will die in that industry during the year. At the end of the fiscal period he compares the actual figures with the estimates and with a few exceptions they correspond closely.

In the foundry industry, the basis has been the same for the two branches. Summing up the experiences of a few years past with the limited number of plants concerned, the following trend is pointed out. In the iron foundries, the actual deaths have exceeded the estimates. In the steel foundries the actual deaths are considerably less than the estimates. This is one possible measure of managment policies.

How great a part of these ultimate figures result from the material handling methods and the working conditions provided for your men, I leave for you to judge for yourselves, but from my observations they are very important factors in establishing the above trend.

Failures Among Foundries

Another measure of management that we have is rather a disastrous one for both parties. It is the number of casualties that we have as far as the foundry itself is concerned—that is foundries going out of business. Here again our company is

closely concerned and very much interested in what enters into these failures of foundries. It is toward the elimination of such disasters that the efforts of our service bureau are directed. Our aim is to spread, broadcast, the better management practices for the interest of all concerned.

Measuring Management in the Industry

I have indicated two factors which might be used to measure management policies and their ultimate effect on the industry as a whole. These figures would be very significant in comparison with those taken from other industries. But your particular interest is your individual plant. What most of you would like is a simple and easily applied yardstick by which to measure your management.

Observations in this industry have shown me that there are some companies who do measure their management. How do they do it? What is the formula? To these questions the answer is through a cost system which is something more than a mere record. They get the facts from their business daily, analyze them, consult their neighbors for comparison, and profit accordingly.

What the Other Fellow Is Doing

At this point I am reminded of the case of a foundryman in the Middle West who married a rich wife, sold out his foundry business and went to the Southwest. He liked the climate so well that he established himself there. Among other things he started a small hennery. One day the rooster of this hennery escaped and wandered afar and in his wanderings came across a very large egg, an ostrich egg. He was rather awed by the appearance of the thing and by dint of scratching and pushing and fanning he brought it back to the coop and pushed it through the hole by which he had escaped. His harem gathered around, anxious to see the new conquest. He drew himself up in accustomed hauteur and said, "Well girls, I do not want to criticize and I don't want to complain, but I just thought I would show you what they are doing on the outside."

What I have to say now is what I have observed other people doing in the various plants I have visited.

Successful Operation Through a Cost System

Not long ago I was in a community in Pennsylvania, where there were two foundries manufacturing light grew iron castings. Each employed about 200 men. The one had about twenty firms on its books and turned out their entire casting needs. The castings ranged from twenty-five to fifty pounds. The cost department, made up of two clerks, was kept fairly busy. The cost records were very simple. Daily the complete performance of each department of the plant was entered in these records. The superintendent of this plant was also very much interested in exactly what he was doing, and from the analysis given to him by these simple records, he was able to draw up a chart which showed him graphically exactly what each department was doing from day to day. He had its cost and he had its output so he could measure immediately the supervision in that particular department. He had a yardstick for measuring and he used it. In addition the fact that interested me most, having studied other foundry figures, were the charts showing the percentage of profit which that man was able to get year in and year out from his production. These charts were particularly striking as he was in a competitive field and business was secured at practically his own price. Some of these figures, I say, were astounding. If I gave them here you would not believe them, but he could show me in black and white exactly what he was doing.

Now let us consider the other fellow. Here was a man who was a very good foundryman. I do not believe that there was a better in the country. His reputation for producing good castings was known far and wide. I asked him about his cost system. He said "Oh, I do not believe in these new fangled ideas that people have brought around. When I want to figure a casting, all I need to know is the price of pig iron; show me the casting and I can give you the price." I don't need to add much more except that the first plant recently took over the other from the bankers.

Ability to Produce but Failure in Business Methods

Not long since I was talking with the director of manufacturing of a large tire company in the Middle West and I asked him particularly about his dealings with local foundries. He said

in speaking of the castings used in tire molds, "We get fine castings; we get them when we want them, we get them just as we do want them; the only trouble seems to be that at the end of each year along comes the fellow who has been making our castings and asks us for money. He is broke. This has happened to us two or three times. I think the ultimate solution is going to be that we will have to put in our own foundry."

Here is another instance of a foundryman well trained in the art of producing castings, but neglecting entirely the keeping of records of production and analyzing these records for their own business stability.

Underbidding Without Cost Guidance

In one of the large automobile centers, I was given the following anecdote. The purchasing agent of a certain company was in the market for a sizeable number of certain casting. Times were not so good and the manager of, I will call it, A foundry, solicited the work and bid 10¼ cents a pound for the casting. This price was a fair one, arrived at from accurate cost data and previous experience he had had with this particular casting. The order was placed with a competing foundry. Being interested in the business and knowing the purchasing agent personally, he inquired as to the reason he did not get the business. He thought that he had shaded his price as much as he possibly could. The purchasing agent said, "It is the same old story. This fellow came in here and gave us a bid of 6½ cents a pound for these castings. Apparently he felt he could do well at that price. However, knowing that he was greedy for the business, I said 6½ cents was a little high. He started figuring and I do not believe that he knew much more about the figures than I did. However he came over and said, "I will take that order for 6 cents a pound." I gave him the order. I knew it was just one of these fellows who likes to pay for working for us. He got that order and he took it, but we are confident that he is not going to make a profit."

This foundryman and his ilk are to blame for such practice and are usually among the missing in a comparatively short time. A purchasing agent who encourages such practices is contributing to a great economic waste and accomplishes no great good for his

own company in the long run. I think he is the more culpable of the two. The foundryman is working in the dark, but the purchasing agent through his experience knows that what he is doing is not right. However, this is an old story. I have seen it frequently in the field.

Castings and Cupola Charging

Let us go back to the subject of material handling. We know this affects the workers greatly. The following observations made in two foundries in the state of Ohio are given to show what a cost system will do in the way of demonstrating possible improvements in material handling methods. We will call these foundries A and B respectively.

A brought his iron and scrap in a wheelbarrow over a dirt runway about 200 feet long to the elevator. The wheelbarrow loads were dumped on the loading platform as was also the coke. Charges were made up by taking the scrap and the metal from the loading platform, placing it on the scale and then subsequently putting it into the cupola. It took seven men, working hard, to perform this complete operation. Rather a heavy charge for the amount of metal handled.

At plant B three times as much metal was melted per day as in the case of plant A. Here three men loaded the cupola. Just what was the difference between the two plants? In the first place, plant B had a concrete runway throughout its foundry yard. Unit charges were made up in the yard on skids, and an electric truck conveyed the skids from the yard to the cupola. In like manner, tipples holding a charge of coke were used to bring the coke directly to the cupola. Plant B went to the extent of making the skids high enough so that the men had a minimum of lifting to transfer the pig and scrap into the cupola. An excellent cost system was used at this plant and one could tell exactly what each department was doing. Plant A had a cost system and had three times as many clerks to operate it as plant B, but this system was merely a recording instrument and not a measuring stick for management. The management of plant B knew very closely what was happening in the other departments of the plant, and had only two clerks to keep the records and operate the cost system.

Costs as a Guidance in Securing New Equipment

Another item by which management may measure itself is in the securing of new equipment. In a Middle Western community I saw two good instances of this. One was a very large manufacturer operating a production foundry. The other was a jobber of large sized castings. A new and improved method of molding was put on the market. The molding machine was effective, a good machine. The managers of the two foundries saw the machine and thought it had excellent possibilities. The production man made an investigation of the machine in another plant to see exactly what it could do and measure it up against his present performance. The result was that he bought the machine and when I talked to him he said that he had cut his molding costs 50 per cent. due to this particular machine. The other fellow in like manner saw the machine and bought three. He thought it was a good idea but when he got the three machines in his plant he did not know what to do with them. He did not have the facilities to give the machine its full tryout or the full benefit of its possibilities. As a result his labor cost was the same as before and he had in addition the charges and operating costs of the machines in question. If he had had a cost system which was operated properly, it would have been possible for him to analyze the situation beforehand. But he thought the idea was good, and bought on the strength of it alone. The production man got the facts and profited accordingly.

Costs as a Guide in Making Sales

I find some foundry managers are ambitious to produce castings for the big manufacturing industries. They will boast that they are making castings for the X.Y.Z. company and say "Why, look what we are doing in here." Well it seems to me that many times they would not boast if they could get back at the true figures and know the facts therefrom. I have seen foundrymen use a cost system to good purpose for dictating to their salesmen just what type of casting it is best to get and what type it is best to leave alone. The big fellow is not always the best fellow to work for. You may have conditions in your plant that make it more advantageous for him to give the castings to you and you can probably operate at a profit. But it is best to be sure that

you will profit rather than to get the glory of working for a large concern.

Simple System Was Effective

In answer to my question, "Have you a cost system?" I have frequently had the reply, "Yes, we have a cost system, certainly. We get our costs on our castings"; and then I have usually followed that up by asking, "How do you estimate your cost?" "Well, now let us start with pig iron, at such and such a price; the casting will cost such and such a pound." It is not necessary to go further. Another alibi is, "We cannot afford to have a lot of clerks around here; that is all right for the big fellows but as far as we are concerned we cannot afford to do that at all." I might say in answer to this objection that the best record and cost system I have seen was in a foundry in Ohio that employed 80 workers. Here was a general jobbing foundry which secured effective results from a simple cost system.

Foundry Anxious for Cost Information

To demonstrate that many foundries are not back in the dark ages as far as costs are concerned, our experience is significant. The Metropolitan Life Insurance Company has a goodly number of foundries insured under its group insurance plan. The services of the Policyholders' Service Bureau are open to these groups. This service covers the whole range of management activities. From inquiries received in this Bureau, particularly regarding costs, we know that the efforts of the American Foundrymen's Association and others are bringing home to foundry managers the value of having and operating a cost system.

The Place of the Local Association

One of the most successful moves toward getting and using cost systems is typified by the results of the activities of a local association in the East. This association comprised a group of about twenty-five foundries. Competition was very severe. Fortunately, about two years ago the association elected a very active and far-seeing president. The association had been primarily an organization of employers banded together to consider relations with the foundry workers. The president of the association conceived the idea that this organization might well be used to secure

the installation of an adequate cost system and help alleviate the cut-throat competition existing. He started out and secured the services of a practical foundry cost accountant. He had a hard, uphill job, but now after two years working he has every firm in this particular district operating under a uniform method of arriving at costs. Demonstrating the facts to be learned from a properly operated cost system assisted him markedly in his early work.

What has this work accomplished? It has brought these foundries away from such situations as the man whom I mentioned using seven men or more to load the cupola. In the association, among other discussions the subject of loading cost was discussed and comparisons made for the benefit of all. The cost man had been successful in demonstrating the advisability of operating on a normal cost basis. It is a striking demonstration to see what has been accomplished in this particular community through securing and using an adequate measuring stick for management.

We feel that the local association can do excellent work in bringing home to its members the advisability of an adequate cost system as a guide to management.

Our hope is that foundrymen generally will give more and more thought to measuring mannagement for themselves. Through this use of the cost system we are confident that the better practices will come more and more to be the universal practices.

CHAIRMAN HAGEBOECK: I believe I voice the sentiment of everyone here when I say we thank you very much. Now we are going to have a man talk to us about a measuring stick or a cost finding method that he has been using for years. It is not a theory but it is the result of practice. There are probably a lot of other systems, but this is one that has proven through years to stand, and that is one reason why we chose this particular one to present to you now as one method of obtaining correct foundry costs, and I take great pleasure in introducing to you Mr. E. T. Runge, the cost consultant of the National Founders' Association.

An Explanation of a Foundry Cost Method

By E. T. Runge, Cleveland, O.

Mr. Chairman and Gentlemen: I have often had the question asked, "Is it really true that there are a number of foundries that do not have correct cost systems? From my experience I would say that 95 per cent either have no cost system or have one that is impractical.

This reminds me a little of a story they tell on the L. & N. which bought up a little road down in Georgia not long ago. The new officials made a trip around the little line to get acquainted with the old employees. Reaching a little town in Alabama, they found among the five or six employees an old colored man. They asked him, "How long have you worked for this road, George" "Thirty-five years." "What wages do you get?" "Two dollars a day." "What did you start with?" "Two dollars a day." "How many days have you been absent in these thirty-five years?" "Never missed a day." "That is a wonderful record. How many jobs have you had in these thirty-five years?" "One job." "What do you do?" "There is one train in the morning and another in the evening and I hit those car wheels with this hammer." "What do you do that for?" "I don't know."

Now, after telling many foundrymen for about twenty years that their method is often wrong, I am further reminded of the man who came up to the zoo. They showed him a giraffe. He looked at it. Then he said, "There never was such an animal and there never will be." But you can go to the other extreme; from not enough you can have a cost system that would be so complicated that it would interfere with the running of your business. Which reminds me of a little railroad out west. This railroad had a little engine; the engine had a big whistle, and every time the whistle was blown the engine stopped.

Cost System Should Serve the Foundry

You should strike the middle of the road, not too little, not too much. When one of our large vessels leaves New York or any other port, and gets out of sight of land out in the great Atlantic or still larger Pacific Ocean, often it gets dark, a storm comes up, the stars are hidden, but the officers are not worried. They look at that compass, that wonder, and it shows them which way they are going. The engine runs that vessel, the freight and passengers furnish the revenue and the profit, but the compass shows them where they are going. For a business, the cost system should be like a compass.

Now I shall choose a grey iron foundry for an illustration. I do this because out of the 6,000 odd foundries in this country over 4,100 are making grey iron castings. The steel foundries are nicely organized. They have a very fine standardized cost method in the hands of an able man; the malleable foundries are also highly organized in the hands of another able man; I do not think the brass foundries ever heard of any system, but the grey iron foundries are now starting to come forward.

All Branches of Foundry Industry Fundamentally Alike

By using a grey iron foundry requiring at least four basic departments, melt, mold, clean and core, you have fundamentally all of these foundries, all classes. Using this for a base, if you have a malleable foundry you add an annealing department, if you have a brass foundry, substitute copper, lead, zinc, etc., for pig-iron; if you have a steel foundry, you can change the material, but really there is very little difference between them fundamentally. They will vary a little in detail, and if you will make allowances, you can apply the illustration, I believe, to any foundry. The grey iron foundry, however, seems to need it most and as there are more small foundries of this kind in the country, I will use for an illustration a grey iron foundry.

Thirty Molder Foundry an Example

I will take a foundry running 30 molders 25 days a month; that would be 750 floors or about 5,000 molder hours; 6 core makers or about 150 days; that is a ratio of 5 molders to one core maker. North of the Ohio River the average is four to six molders to one coremaker; further south it runs two and three

to one, but for the illustration I will figure five molders to one coremaker.

Now let us assume that this foundry runs one month on one kind of casting only and let it produce 400,000 pounds. In the next month, let it produce another kind of casting, making 500,000 pounds; the third month on still another kind of casting, making 200,000 pounds. For example, we will use $22.00 pig iron delivered and $10.00 coke. We have a cost of $4,840 the first month for pig and coke, about $6,000 for the second and $2,450 for the next month. Then we have cupola labor and expense of about $1,510.00 for the first month, $1,560.00 for the second, and dropping to $1,250.00 for the third month. The molding labor is the same for each month and using about $7.20 a day, would be about $5,400 per month. The mold expense we will call the same ($5,400).

After leaving the molding room, we have a shipping and cleaning expense of about $2,800.00 for the first two months and $2,500.00 for the last month. The core labor for these six men (150 days at about $6.00 a day) is $900 a month; and the core expense about $1,600 for the first two months and $1,500 for the last month. Divide that total cost $22,450.00 by 400,000 and you get a cost of $0.0561 per pound for the first month, $0.0473 for the second month and $0.0970 for the last month. This is, therefore, an actual cost, so there is no argument, for we are making only one kind of casting each month. If this were the case in all foundries, then that is all there would be to a cost system; however, you do not make only one kind of casting.

Combined Figures Over Long Period of Time Mean Little

Now let us assume that we arrive on the scene after three months are completed and that you and I are outside parties, we have no access to these monthly figures but they give us a jumbled up lot of combined figures for the three months. We find the total for three months for thirty molders to be 2,250 floors, 15,000 hours; for the coremakers 450 days, and the product is 1,100,000 pounds of good castings. Then we figure our pig and coke, our cupola labor and expense and the total is $17,600 or the cost of melting those castings at the spout. If you allow it to pour on the ground and do nothing further it has cost you $1.60 per

hundred pounds. Molding labor will be $16,200 or $1.47 per hundred pounds; molding expense the same or $1.47 per hundred pounds. Now that is 100 per cent of the molding labor, it is also $7.20 per floor, and it is $1.08 per molder hour. We will come back to this later.

To clean and ship the cost is $8,100 or 74 cents per 100 pounds. This is 50 per cent of the molding labor, $3.60 per molding floor or $0.54 per molder hour. Your core labor is $2,700.00

Table 1

BASIC PROOF

Operation	1st month (4000,000) 533 pounds per day	2nd month (500,000) 667 pounds per day	3rd month (200,000) 267 pounds per day
Melt @ .0160..... Per Pound	8.50	10.70	4.26
Mold Labor 1 day.....	7.20	7.20	7.20
Mold and Clean Exp. 150% of Labor..... 10.80 per day 1.62 per hour	10.80	10.80	10.80
Core Labor.....	1.20	1.20	1.20
Core Exp..... 175% of Labor	2.10	2.10	2.10
Total Cost.....	29.80	32.00	25.56
Cost per Pound.....	.0560	.0479	.0956

or one-fourth of a cent per pound. The core expense is $4,700 or 175 per cent of the core labor. The total cost per pound is 5.75 cents.

The idea is now to get as close as practical to the true cost. Let us try and see if we can make a basic proof from these figures. We know that 400,000 pounds from 750 floors, makes 533 pounds per man per day, 667 pounds per man per day for the second month and 267 pounds per man per day for the third month. The molding labor is $7.20 for a day; the overhead is $10.80 (that is mold and cleaning expense). Why make two operations if you can save one, so 150 per cent of $7.20 is $10.80.

Table I gives the condensed data of the basis proof.

Exact Costs Not Practical

That is about as close as I can come to the exact cost. I never got a correct cost in my life, because it costs too much, but I wish to get a practical cost, even though by thus working it, I am generally a little off the true cost. My cored castings, while some claim they are often high, are often a little lower than the real cost, and my plain castings are a little higher, but that is as close as I try to come; I do not claim to figure an accurate cost.

Comparison of Method

Now I will show you several other methods. This method is what I have been using for about twenty-five years and the man who may have invented it probably died, so I call it the Runge method, as I have not found anyone yet to dispute the claim. We have another method which I will call A. By that method you take the entire amount, $65,500, divide it by 1,100,000 (lbs.) and you have a cost of $0.0595 per pound, just an average cost. Over 90 per cent of the foundries are using the A method.

The next or B method is where they take the pig, coke and cupola labor only at so much per pound. In our example it would be $0.0135. The molding and core productive labor is charged direct to the job. All other expense is found to be a certain percentage of the core and molding productive labor combined. In this case it would be 168 per cent. That I will call method B.

I have still another method which I will call method C. The pig iron and coke is found to be so much a pound, $0.0121 in our example. The molding labor is charged direct, the core labor charged direct, and the core expense as a percentage against that labor. All other expense so much per pound of castings, which in this case would be $0.0260, based on this example.

I have another method, which I will call D; pig iron so much per pound; the core material so much per pound, and mold and core labor charged direct; all other expense per pound of castings; in this case $0.0282.

Now there is a gentleman out in California, Mr. Hax, who has done a great and good work for the California foundries, and I am glad to give him a good word. In this method he takes the melt cost (in this example .0150). He is a little lower than I

am, because he puts some of his expenses in other places. The mold and the core labor are charged direct and all other expenses charged so much per mold and core labor hour ($1.67 in this example). The molding and cleaning expense can be used by any one of three methods; percentage on productive labor (so much per

Table 2

PROOF

2250 (Floors) x 1000 (Lbs.)=2, 250,000 Lbs.
Produced in three months.

Pig and Coke	$27,200.00
Cupola Labor and Expense	$ 5,000.00
Mold Labor	$16,200.00
Mold and Clean Expense	$26,000.00
Total Cost	$74,400.00
Cost per Lb	$ 0.0331

Or let us run Foundry for three months on 200 Lb. per day cored casting only:

2250 (Floors) x 200 (Lbs.)=450,000 Lbs.
Produced in three months.

Pig and Coke	$ 5,450.00
Cupola Labor and Expense	$ 4,000.00
Mold Labor	$16,200.00
Mold and Clean Expense	$23,000.00
Core Labor 2250x4.00	$ 9,000.00
Core Expense	$14,200.00
Total Cost	$71,850.00
Cost per Pound	$ 0.1600

floor) or so much per hour, this being flexible. The core expense I generally use as a percentage against the productive labor. Now I will try and figure several castings for you—a 1,000 pound floor per day, 533 pounds per day plain, 533 pounds per day cored, 300 pounds cored, 200 pounds cored and 150 pounds cored.

Proof of Method

Before I start let us try and prove that the method is somewhere near correct. I will run the entire three months plant on the 1,000 pound casting first. Refer to Table 2.

Now, on these other castings, I have figured them all out, so will not figure them in detail here. (If any of you gentlemen wish to figure any of those, you are at liberty to do it.) I have done it and if you will take my word I assure you that I have figured it correctly as far as the clerical work is concerned.

I have mentioned the different methods on those casting called the Runge, Hax, and A, B, C and D methods. By referring

to detailed table of comparisons which follows you will note on the 1,000 lb. per day plain castings, the Runge method shows a cost of $0.0340, the Hax, $0.0333; method A, $0.0595; method B, $0.0328; method C, $0.0453; method D, $0.0461, and our proof,

Table 3
COMPARISON

Method	1000 Pounds per Day Plain Cost per Pound	533 Pounds per Day Plain Cost per Pound	300 Pounds per Day Cored Cost per Pound	200 Pounds per Day Cored Cost per Pound	150 Pounds per Day Cored Cost per Pound
Runge	$0.0340	$0.0497	$0.0943	$0.1610	$0.2095
Hax	0.0333	0.0494	0.0953	0.1635	0.2122
A	0.0595	0.0595	0.0595	0.0595	0.0595
B	0.0328	0.0497	0.0957	0.1635	0.2138
C	0.0453	0.0515	0.0804	0.1291	0.1592
D	0.0461	0.0523	0.0731	0.0984	0.1170

you will note shows $0.0331. I am a little high and Mr. Hax is close. However, as Mr. Hax and myself are pretty close all the way through, we are either both wrong or both right on these castings. On the 300 pound cored casting (there's two dollars for core) I get $0.0943 and Mr. Hax gets $0.0953. The proof comes out very close, it is a split between the two of us. On the 200-pound cored casting ($4.00 for the core labor, $7.20 for the molding labor) I get $0.1610 per pound and Mr. Hax gets $0.1635; the proof on that comes out practically even, $0.16. I happen to be a little closer on this one.

Now let's refer to Table 3.

Clerical Force Should Be Small

Mr. Hax's cored castings are a little higher than mine and my plain castings are a little higher than this, but there is quite a variation and quite a difference between these six methods to say the least. This is about all there is to a practical method and little work is required in making up your departmental analysis card. This may take a day a month in the average foundry. It does not require very many clerks; we have one foundry running 70 molders, figuring the cost on every casting and giving an individual price. They have two men on this cost work. But most of the foundries we handle get along with one man.

Discussion—An Explanation of a Foundry Cost Method

CHAIRMAN HAGEBOECK: I think Mr. Runge should have a hand on that talk. The cost committee is certainly most gratified by this attendance and I think it might be interesting to note the cross section of the men here, not anything definite but a general idea. I would like to ask for a show of hands as to how many here are connected with corporation foundries that are not in the commercial field, foundries that are simply making castings in a foundry that is a department of a manufacturing concern.

A show of hands indicate a cross section of the gentlemen present, representing about as follows:

Corporation foundries—about 30 per cent.
Corporation foundries also doing jobbing work—about 40 per cent.
Jobbing and commercial foundries—about 30 per cent.
Executives or owners of foundries—about 25 per cent.

MR KELLY: I would like to ask Mr. Runge how he takes care of his office and rental in his cost? That is something I did not get clearly. Are you going to allow something for your rent on your foundry and for your office overhead, etc.? Don't you add that to your cost in figuring cost on your castings per pound?

MR. RUNGE: When I first started out twenty years ago in the foundry cost business, I took what was on the books and, after an awful fight, I got them to agree to allow me to put down depreciation. Later, we evolved and began to add a certain percentage for bad accounts. Then we got so bye and bye that the officers would vote themselves a salary, and we put in administration and salary expense, and now I even put 6 per cent interest on the investment. Figuring that to get your cost, you must force your selling department to at least keep up your plant and prevent obsolescence, pay all your expenses, pay your administrators a living salary and pay at least 6 per cent interest on the investment, which you could get by loaning your money out. If there is anything I have left out, it is going to go in in the future, but I put in everything I possibly could that belongs there.

R. CRAWFORD: What effect has that cost system had on any particular group of foundries that you operate? Take the Cincinnati group; what results would you tell us have been obtained by that particular group through using your cost system?

MR. RUNGE: I do not claim that I ever helped a foundry, but I have always claimed that it never hurt one. Now, in Cincinnati, they have a little group they call the Tri-State. For seventy or eighty years the

foundries had been the goat; they had been failing. About seven or eight years ago they were kind enough to ask me to start a standardized proposition where we compared fundamental costs, and since that time no foundry has failed, and, even though some ran as low as 40 per cent of normal, they made a profit. Instead of the foundries failing, sometimes a customer failed.

R. CRAWFORD: Say we put in a corporation shop that runs low on their product and find it necessary to go out into the jobbing field to compete with the jobbing foundry; what effect have you found under those conditions in regard to competition? Has it hurt the jobbing foundry or benefited the corporation shop, and to what extent?

MR. RUNGE: I won't say this covers every case, but I will cite an instance that came to my attention about three or four years ago. This company had a little foundry of about 15 to 20 molders making its own product, and business got dull, so their product dropped to about 40 per cent of their normal. It seems as though their habit was to believe that they did not have any overhead in that foundry—all the administration and other expense was borne by the rest of the business, so all there was to the foundry was simply pig iron, labor and supplies and superintendent's salary and operating expense, and they did not have all of that prorated. Thus they left out quite a little of that expense; in other words, they favored that branch of the business. Mr. Superintendent goes out and he is able to make some pretty attractive prices. Well, after a little while their own business picked up and then, of course, they kicked all that jobbing business out and went on their own line, but they left a rather demoralized bunch of jobbing foundries to carry the bag. That applied to this one foundry. Unless the private foundry (that does a jobbing business) puts in all their overhead, they are apt to deceive themselves and, not getting their true costs, would not be able to compete intelligently with foundries that are in business to make their living making castings. So ordinarily I should say that it does not do the industry much good.

MR. THOMPSON: I would like to ask Mr. Runge what he figures the cost on total tonnage of castings for the month, whether he includes the entire tonnage of gates and castings?

MR. RUNGE: My castings are castings shipped from your shipping room to your customer, and they have never come back; you get real money for it; that represents the true bona fide tonnage that you get real money for; that is your real product. If you make 1,200,000 pounds of castings and only receive payment for 1,000,000 lbs., your product is 1,000,000 lbs.

MR. THOMPSON: Do you include the cost for the melting of gates and sprues?

MR. RUNGE: Suppose it takes 108 pounds of metal to make 100 pounds of good castings, castings that never come back; now, in addition

to that there is cupola labor, fire brick supplies, etc., also power, and a few other things that make up the balance. The $1.60 represents the iron poured out of the spout.

If you turn in and make sash weights, it takes your melting molding department only. Now, if you clean the castings that is an extra expense. I might have a core factory in Syracuse and supply them to every foundry here; how easily they could take my invoices and (say my cores cost 10 cents apiece) add that to the casting. What difference does it make whether I run that core factory or you? A plain casting has no license to bear any of the cost of a core that does not go into it; in other words, you would make the plain castings cost too high and thus favor the cored castings.

J. S. STUCKIE: Under what head do you class labor and material and does that price in that casting include shipping to destination?

MR. RUNGE: I make the cut-off when the iron pours out of the spout; the molding department then carries it and so on. Each department delivers its product to the next. The molding department delivers it to the cleaning room; that is a molding expense. Suppose the customer said, "I will buy your castings not cleaned"; what drops off? Cleaning. Or suppose a customer says, "Cancel the order." Well, we have made the cores. All right we will charge you for the cores; that is the core department. Or, as happened in Covington, Kentucky, during a shut down several years ago when they needed certain castings to help out on a back order, the foreman and one or two men made some molds, went next door, carried over that iron and poured it in the mold and were charged 3 cents a pound for it.

If a foundry sends in castings to another foundry to be cleaned only for them, you thus have a separate business. Imagine the cupola in Illinois, the molding room in Pennsylvania, the cleaning room in New York and the core room in Indiana; you would not have any trouble whatever in keeping those expenses separate, but because those departments are all together it sems hard to keep them separate, yet they are as separate as if they were in different states.

J. S. STUCKIE: I get the idea that the price on those castings means delivered to the concern that buys the castings?

MR. RUNGE: Oh, I always figure everything f. o. b. plant, net price, no discount. You add that to the individual cost price, if you deliver, because you might send the castings to California or you might send them to Albany and thus could not put it in the overhead.

J. S. STUCKIE: How about your flask, labor and material?

MR. RUNGE: Once I looked at the equipment in three companies and found the pattern and flask material was about the same. In one it is down for $50,000, $180,000 in another and one dollar in another. I could not get any depreciation rate on this basis so I charged all the new

flasks and the bottom boards as far as made an expense, because they spent the money, and I charged that as real depreciation.

MR. POWELL: In making your pro rated charges for overhead, do you charge each department with its pro rata payment of the fixed charge?

MR. RUNGE: Yes, sir, to go over it quickly, if we make a building depreciation, we would not charge as much depreciation to the cupola section of about 1,000 square feet as we would to the molding at about 40,000 or the core room at 3,000, or the cleaning room at 5,000; we would divide that up on the basis of what space each department used. Say an average machinery depreciation is 10 per cent in a foundry, we charge that to each department on the basis of what they have in them. I think you are getting around to the power charge. We charge very little power to the core room, but a lot to sand blast, yet very little building depreciation. Now when it comes to the old bugaboo of administration, there are five or six ways of charging administration expense, but in order to get it in—I may be wrong—I charge on the basis of percentage of total labor used by each department, and thus get it in. That is the reason I do not get accurate cost. My main object is to see that it is not omitted.

MR. BOBBIS: What do you allow for loss in melting?

MR. RUNGE: In a grey iron foundry we generally figure that 108 pounds of purchased metals will make 100 pounds of good castings. If you have a cinder mill, it will run about 7 per cent. I have not studied enough of the electric furnace yet. Your steel foundries will run to 20 per cent under ordinary methods; your brass foundries four to five on brass and about 6 per cent on aluminum.

R. E. BELT: My understanding of your example is that you are assuming normal production, whether it is productive hours or tonnage. What would happen if operations were 40 per cent of normal?

MR. RUNGE: I would figure my actual cost 40 per cent. Then I would turn it into normal and see what the spread was between the two, and thus know how much of a gap there was to fill.

CHAIRMAN HAGEBOECK: Mr. Belt, will you ask your question again?

MR. BELT: My question is, what disposition should be made of idle expense during periods of partial inactivity? I understand from Mr. Runge's example that he is distributing all overhead regardless of operation. In time of depression the costs are abnormally high and you cannot hope to dispose of your product at your book cost.

MR. RUNGE: Answering your question, supposing we would find that a casting cost four cents normally; suppose we should find that it cost six cents abnormally; we thus have the comparison, a difference of two cents. Now, going into the market, we thus see how much of that gap there is to fill and this will not interfere with the selling policy or anything else. I try to get actual costs and normal costs working parallel

in those peculiar cases, which is really another way of putting a certain percentage of overhead into idle equipment, or another method of arriving at the same thing but getting the two variables, one actual and one normal. This illustration is simply an example based on running twenty-five days a month.

CHAIRMAN HAGEBOECK: I would like to ask this question. I have consulted many men on this very point of overhead. What are you going to do when you are running 50 per cent of capacity? It has always seemed to us that it is a problem of getting an average of what your overhead should be when you are running normal (by normal I mean from 80 to 85 per cent of capacity). If you use this normal overhead you will build a bank or reserve during good times and you will use this reserve during periods of slack production. How many here do figure and think that we should figure normal overhead in times of depression as well as in good times? (A very definite percentage of those present expressed themselves as agreeing with the chairman.) Now, Mr. Belt, I think your question is answered.

MR. POTTER: I wonder if it would be legitimate to set up a reserve item as an expense item in good times, to serve as an expense in low times and pick it out from this reserve and put it as cost?

CHAIRMAN HAGEBOECK: That is just a matter of bookkeeping. You can go along and if your overhead ought to be 100 per cent and shows up 150 per cent one month, it should not alarm you, because only six months ago it was only 80 per cent.

MR. GIFFORD: I disagree on the question that has just been put. I think there is more crime, commercially speaking, done by adopting that policy than any other thing in connection with the foundry. If you adopt a policy of saying, "We are up against an abnormal overhead, we will just forget it," that is the reason lots of people lose money during a depression. There is one time that you want to know what your actual overhead is, during a time of depression; you can use and charge off any part of that to abnormal overhead, but most people are simply kidding themselves and losing sight of the fact that they are not doing the things that can be done during that period of depression.

CHAIRMAN HAGEBOECK: I agree thoroughly that you should know your overhead all the time. Does anyone disagree with that?

MR. GIFFORD: We have four foundries, and that is a very debatable question. In 1921 and 1922, when the depression was on, we found it practically impossible to force them into any other attitude than that they were up against an abnormal overhead and it could not be helped, and they would have to take it on that basis. One plant adopted straight overhead. In another plant we adopted the basis that the abnormal condition must be met and the foundry superintendent was able not only to meet it, but he actually decreased the non-productive labor per ton in his foundry by over a third compared with what he was operating under normal conditions.

CHAIRMAN HAGEBOECK: That illustrates that during a slack period you can get a lot of costs that you cannot get when you are running 100 per cent.

MR. BROWN: As I understand it, there is not clearly brought out at any particular time what portion of the cost found is due to the administrative and depreciation, those constant charges. It is worked into the fabric of cost, and it is not clearly brought out in any particular portion. Is that correct?

MR. RUNGE: As I stated, the four departments, in making out these examples, I have charged their proportions on a different basis. We will say 20 per cent of the horsepower went to the cupola, 5 per cent into the core room, 50 per cent into cleaning and the balance into molding; then we might say that depreciation was charged to each of the four departments. The supplies of course were actual, molding supplies into the molding department, etc.—taxes on the basis of the value of equipment in the departments. Of course I have not shown all those details, because that is technical; I am simply showing fundamentals.

MR. BROWN: I must have stated my remarks rather indistinctly, because I do not think you understand them. Suppose that a casting is brought out that costs 5 cents a pound and for the sake of argument we will suppose that one cent of that was due to constant charges of plant; we know that there are certain charges that are constant. Now it is extremely necessary in making prices on castings, that the man who makes the price shall know how much of that cost is due to those constant features and how much is due to actual operation, because, as your operation goes down, your costs go up, due to that administrative expense, and if you are going to make your prices on the basis of costs so brought out, without distinguishing in your mind and your treatment between the difference in those two kinds of costs, your prices will go up as your operation goes down, and the result will be that you will rapidly raise your prices to a point where you cannot sell any goods.

MR. RUNGE: That would come under Mr. Belt's question. If you get your 40 per cent and also your normal costs, you have your two cost limits. After you know your actual cost, and your normal cost, then you decide your own selling policy.

E. H. CLEMENT: I want to ask Mr. Runge how he figures overhead items that come once a year, such as insurance and taxes? Do you use the previous year?

MR. RUNGE: If I am making monthly costs, I take one-twelfth of my insurance, one-twelfth of my taxes, one-twelfth of anything we can budget, that is a general or fixed expense; power is actual; you might have twice as much power one month as another but when it comes to these general fixed expenses that the gentleman had in mind, we would run that on the basis of one-twelfth. Of course it is possible to go finer and get on a unit basis, if you know what your tonnage is going to be

for the year. That is a problem you do not know, so while we are working the best we can, we have divided it up one-twelfth for each month, but that is a small item, it might run from half a cent to a cent a pound, as you stated, and if you are off 10 per cent on 10 per cent, you only affect the whole one per cent. Usually I use last year's taxes plus say 5 or 10 per cent for the current year, as they are seldom less but generally higher.

MR. CLEMENT: Those costs might be considerably higher for the current year than the past year, and you are liable to get off.

MR. RUNGE: We only use the costs of the past year until we can arrive at figures for the coming year showing where they have been changed; the moment you find there is a change, for or against, you are naturally going to remodel your estimate; that is the advantage of having the monthly comparison with the past year. Some of our companies have it for nineteen or twenty years; the malleable iron people will take, say 65 per cent of the maximum, for normal, and that will constitute a running of about 20 years. Some brass foundries take 75 per cent and many grey iron foundries 80 per cent.

CHAIRMAN HAGEBOECK: Is it a fact that the charge for heating a plant is just as much in July as in December?

MR. RUNGE: Yes, sir, because suppose your heating expense was $6,000 a year; for the six winter months I do not charge $1,000 per month. I charge $500 a month for the whole year. Why you might give that quotation along in July and the order come in in December, so in that case I do not take the actual heating cost, I try to take a practical cost, depending on a study of each factor going into those costs, and while a number are general there are some that will be variable.

CHAIRMAN HAGEBOECK: I want to repeat that Mr. Runge said in his talk that in 25 years' experience he never figured an accurate cost. Those of you who were at the National Founders' Association meeting last year may remember the remarks he made there. Somebody asked him a fool question, I don't know what it was, it was a very complex question, a question you could answer two ways and still be wrong. He said, "I believe in running a foundry, and not running a cost system," and that is his theory all the way through, that he is trying to arrive at these costs without making them burdensome.

MR. BELT: My experience in foundry costs has been this: I agree with Mr. Runge heartily in nearly every statement he has made with the possible exception of the distribution of idle expense. He has not covered that so very clearly in his illustration. My experience in foundry costs has been that there are certain fixed plant charges, such as depreciation, taxes, insurance and general administration, that fluctuate directly with activity, and such charges I think should be distributed on some basis of normal production, whether it is productive hours or tonnage or whatever is the most stable factor. Operating expenses can be controlled quite largely as production varies, and there is not the same necessity to adjust

those expenses, depending upon the rate of business. I find that if you take the general administrative expenses, so-called, fixed plant charges and consider them in the light of operation, we are getting fairly accurate cost of production.

CHAIRMAN HAGEBOECK: What do you mean by "in the light of operation"?

MR. BELT: Well, if operations were 50 per cent of normal, carry 50 per cent of fixed plant charges into production costs, and the other half directly to profit and loss account or reserve. If you carry reserve, then you can use your cost figures for price making purposes, and should be able to get business on that basis. If operations are 40 per cent of normal and you are charging all your overhead into cost, you cannot get much business in time of depression at your book cost figures. Others are not so figuring costs and are making prices on the basis of their normal cost, you might say. I think the distribution of overhead expense and particularly the distribution of fixed plant charges is one of the most important phases of cost accounting in the foundry industry. It is really the only troublesome thing in foundry cost accounting. There is no necessity for having a foundry cost system complicated. It is not a complex operation to manufacture castings and the cost system should be just as simple as is the manufacturing process.

A MEMBER: It would look to me as though under neither the Runge or the Hax method of building costs is any of the molding overhead applied on a weight basis. Apparently it is applied more on a molding labor basis. Why don't you use any of the weight basis?

MR. RUNGE: The only place I use a weight basis is in the melting. A weight basis is as long as a piece of string, and again so many foundries will not or cannot give you correct weight. The law forces you to keep a payroll and I know that your payroll is right, and my hours and my floors are right, and until I can get an absolutely correct physical unit or weight proposition I intend to stick to something that I know is fairly right and that works out much more practically than anything I know of at the present time.

CHAIRMAN HAGEBOECK: There are lots of foundries that distribute a part of their overhead on the tonnage and part on direct labor. Mr. Runge carries his mostly on a direct labor basis.

A MEMBER: Do I gather from Mr. Runge's answer that if you had faith in your weights you would be inclined to apply some of your costs, such as sand, on a weight basis?

MR. RUNGE: Well, that goes a little by the molding surface. Supposing you had two castings that were identical in surface; one was hollow and the other was solid, and they took the same amount of sand and the same size flask, yet one might weigh three times as much as the other—a solid ball and a hollow ball. It might take as much labor for one as for the other, but the weight would vary so much that I do not

get it correct, hence I am on the safer side to use the labor basis. You would have to departmentize and then you would need a cost man for every molder and it would cost too much; that is the reason I said that I never get an accurate cost; I only try to get a practical cost; I try to get what we call, in automobile parlance, a fool-proof method. I admit that it is not correct, but I wish to make it practical. The idea in having a cost system is to make some money, and if you have a cost system, of course you might make it a little more accurate, but the real idea in running a business is to make money.

W. D. MOORE: I want to know whether I understand correctly how you distribute all indirect charges, assuming you have a foundry business in which you make three different types of castings, very light, medium and extremely heavy; how do you arrive at the proper proportion of indirect charges that shall go to the cost of each of those types of casting? As I understand, you do it on a dollars and cents basis.

MR. RUNGE: The only thing I put on a pound basis is the melting. The overhead, after you have charged what belongs to the melting, I handle it in three different ways against the molding productive labor as a percentage, or per molding floor, or the molding productive hour. That is a detail. If I should attempt to explain all these technical things, it would take more than by alloted time. I am just explaining fundamentals.

W. D. MOORE: Mr. Runge has answered my question; he is doing it on an hour or dollars and cents basis, not on a pound basis.

MR. RUNGE: Yes, except on the melting.

CHAIRMAN HAGEBOECK: I think Mr. Runge leaves the impression from some of these charts that he gets an average cost over a period, we will say, over a month. I think that ought to be brought out because there are foundries that do that very thing. To my mind that is just good practice in long division, to know your average cost of all your castings.

W. T. BARTH: The way I figure my foundry cost is, I figure every heat and then I add up at the end of the month and when the year is up, I take my profit charge off my expense and if I am getting ahead considerably, I think I am doing pretty well.

MR. PERRY: We are going to have some organized effort to have a uniform cost system adopted and we are going to have some reports through our A. F. A. bulletins so that we can compare our costs and see if we are doing as well as the other fellow, or if we have anything we can give to the other fellow. Is there some organized effort going to be made to make this a uniform cost for comparison?

CHAIRMAN HAGEBOECK: You are the members of the A. F. A., and anything you want to do, you can do it. It is is largely a matter of interest, first. You have displayed some interest here today, but you never have before, generally speaking. Now we would be glad to entertain any ideas you have along those lines.

A MEMBER: I would like to ask what success has been made in this very same subject which was brought out here last spring in Syracuse? Have any of the manufacturers applied your system?

MR. RUNGE: About six or seven months ago ten foundries were kind enough to ask me to standardize and give comparisons quarterly. Now, if there is any member of that Syracuse group here who wants to say whether it is good, bad or indifferent, I'd rather they would say it. I know they still ask me to come; maybe they are satisfied; maybe they haven't got on to me yet.

W. L. HINDS: We are one of the ten; we are very much pleased with what Mr. Runge has done. We feel that we are on the way to organize standardization among our local foundries that is sure to be very profitable to everybody. Prior to Mr. Runge coming here, we always had a lot of discussion and seemed never to get anywhere, about costs. I feel that Mr. Runge, if he keeps on the job, is going to bring us to the point where we are going to make some money. We are very much pleased with what he has done.

CHAIRMAN HAGEBOECK: Thank you. Let us confine this discussion to experience. Mr. Tuscany, of the Ohio Foundry Association, won't you tell us of your experience?

MR. TUSCANY: I came here to listen, but I will say that Mr. Runge has been doing what Mr. Hinds states he has been doing at Syracuse. We have organized a number of centers in Ohio. We are not through in Ohio yet, and some of you fellows know there is a bad combination in Ohio. We are going through the state and continuing the work Mr. Runge has started. In Cincinnati there are several groups which have been formed, with probably a dozen larger centers in Ohio being formed into groups, meeting periodically, making comparisons one with another.

A. E. BARLOW: I simply want to make a few remarks regarding the advantages of a local association. In Newark this cost system will not reach its full value until the local group adopts it. It is more than an individual matter, it is a group matter. Our competition is local, and therefore the foundries in a city or a district must get together and adopt some of these systems or these ideas. At Newark we have done that with considerable success. We have a great deal more to do, but I want to testify to the value of the association in cost accounting. I could enlarge on that, but there is hardly any time; however, I want to emphasize the necessity of getting together in local groups to put this over, otherwise this talk this afternoon and this discussion is very nice, but it will not be effective.

W. B. PERRY: If this is the proper place, I would like to make a motion that a committee be formed to put this matter before us in a logical, concrete way so that we can study Mr. Runge's method and form a definite return from it for those who would like to cooperate.

CHAIRMAN HAGEBOECK: In other words, you would like to have the committee continue its work and come back with something more definite in a reasonably short time?

MR. PERRY: Yes sir.

The motion was seconded and unanimously adopted.

R. CRAWFORD: Before this meeting adjourns, I would like to make a suggestion. This meeting is representative, and there is no use of our waiting three months or six months, or until next year; my motion would be that you appoint three or five representatives from each state to cooperate and do what we think is most beneficial. In that way I believe you will get further.

CHAIRMAN HAGEBOECK: As a matter of fact, both of those motions ought to be simply recommendations to the board. We will put them in that way. Your suggestion is that you have a committee of three to five from each state?

MR. PERRY: If possible, from this audience; the states are pretty well represented now, and if you make it that those three or four have a meeting before we adjourn Friday, I, for one, will be glad to cooperate.

The motion was seconded and carried and the meeting was then adjourned.

Some Refractory Problems in the Non-Ferrous Electric Furnace Casting Shop

By G. F. HUGHES*, Bridgeport, Conn.

This paper is the result almost wholly of the writer's experience with induction and rocking arc electric furnace melting in the casting shops of the Bridgeport Brass Co. This company was the first to adopt the induction furnace melting as the preferred means of casting brass billets, slabs and tubes for extrusion, rolling, and drawing; and its aim since that time, has been to make its melting 100 percent electric in a type of furnace in which metal is melted through heat generated in itself by currents induced in all or a portion of the charge.

The first part of this paper deals with yellow brass which today presents no problem of a serious nature; the refractories on the average work in a satisfactory way. The chances for improvement are to increase the life of furnace linings which now last a sufficient time to make their replacement cost a small percentage of the total cost of melting. Some improvements may also be made in reduction of electrical losses through refinement of design and refractory insulation. The second part discusses briefly the experience with linings in a rocking arc furnace used in melting copper-tin alloys at temperatures which as yet the induction furnace lining has not handled successfully. In the third part is set forth the work which has been done and which remains to be done in order to bring the induction furnace into the field where its use may be universal in non-ferrous melting. It is not necessary to repeat the oft times mentioned reasons why better metal can be produced if melted in a furnace where the heat is generated in the metal itself, where atmosphere in contact with the bath can be controlled and where heat input and temperatures can be readily determined.

In ordinary non-ferrous casting shop practise there are two general types of melting mediums when considering the refrac-

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tory problem. First, there is the furnace in which the refractory container for the metal is a heat conductor, namely, the ordinary graphite-clay crucible used in the pit fires; or, various externally fired coke, oil or gas furnaces. On the other hand, there is the type of furnace in which the refractory container acts as an insulator, such as the various types electrically heated; also, the reverberatory type of oil or gas fired furnaces.

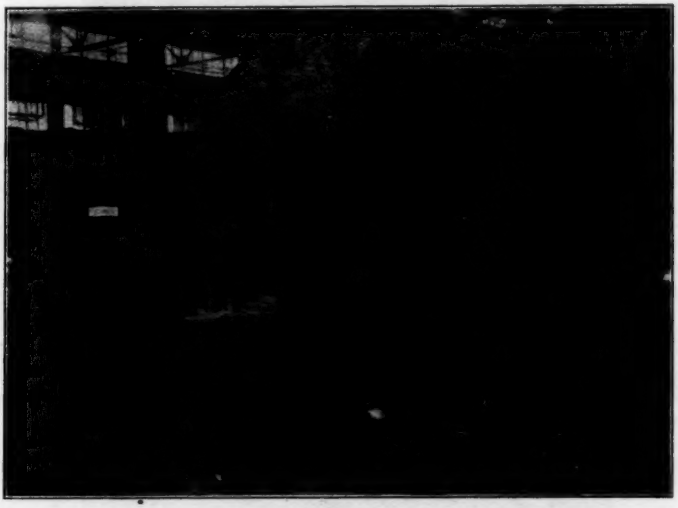

FIG. 1—SHOWING GEARED RIM, CHARGING DOOR, POURING SPOUT AND ELECTRODE HOLDERS

It is with the electrically-heated furnaces in which the refractory part of the furnace acts as an insulator for the generated heat, that this paper has to deal. The manufacturers of crucibles for coke, oil, and gas furnaces fired externally have spent considerable time and money for the development of a refractory metal container that will meet the necessary requirements in the melting of all types of non-ferrous alloys. Consequently, they are in a better position to present the problems existing in the developing of this type of melting than is a manufacturing concern

whose experience for the past eight years has been almost exclusively with electrically-heated furnaces whose refractory metal containers act as an insulator.

Types of Furnaces Used

In melting non-ferrous alloys by means of electrically generated heat there are three types of furnaces most commonly used, namely, the resistor type, the arc type, and the induction type. The experience of the casting department of the Bridgeport Brass company has been almost entirely confined to the last two types mentioned; although several years ago, a furnace of the resistor

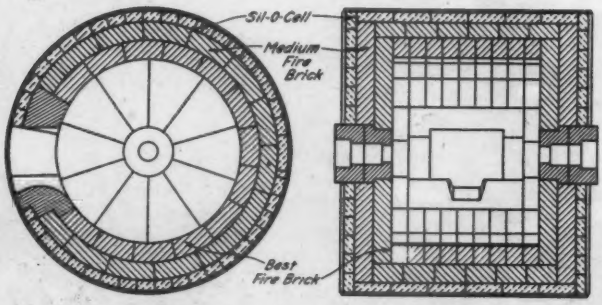

FIG. 2—CROSS SECTION VIEW OF ROCKING ARC FURNACE SHOWING METHOD OF LINING

type was used for a time. As both of these latter types of furnaces are well known, it is hardly necessary to go into any detailed description concerning the principles and operation of these furnaces in which the refractory part of the furnace acts as a heat insulator as well as the metal container. Figs. 1 to 4 show three photographs and a cross section view, of the two different types of electric furnaces used in the plant with which the writer is connected.

Rocking Arc Furnace

The rocking arc type of furnace used consists of a steel drum-shaped shell with a rectangular shaped vent in the peripheral wall

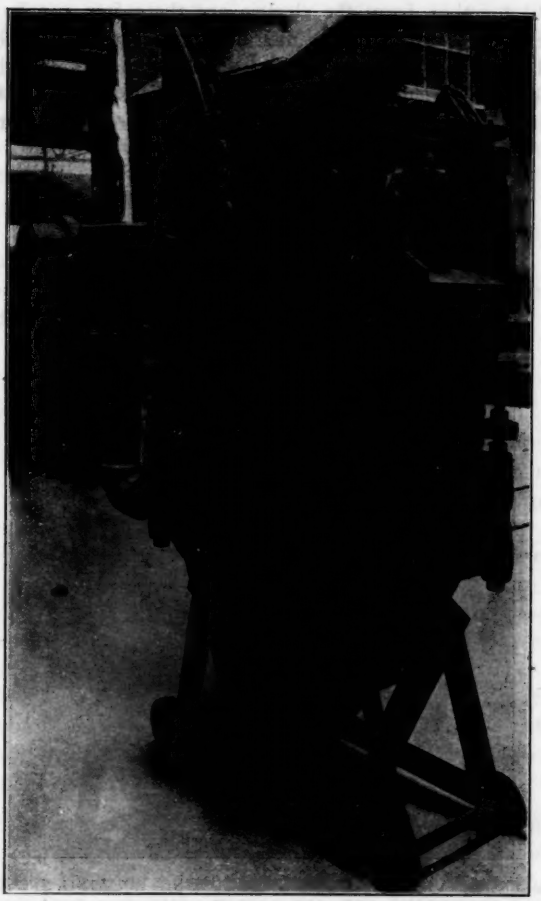

FIG. 3—REAR VIEW OF INDUCTION TYPE ELECTRIC FURNACE, SHOWING POSITIONS OF CHARGING DOOR

for the purpose of charging and pouring, which opening is covered, when operating, by means of an iron door backed with refractory. Through circular openings in each end of the shell are introduced carbon electrodes. The two electrodes when

brought together form the electric arc thereafter supplying the source of heat necessary for melting the charge. Each electrode is held securely by a water-cooled bronze bushing bracketed to the outside of the furnace shell and by a refractory brick bushing in the lining wall in such a manner that each electrode is adjustable in

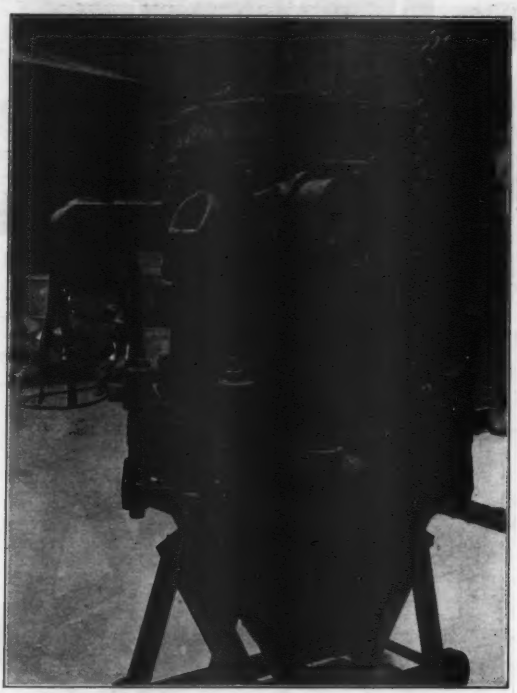

FIG. 4—FRONT VIEW OF FURNACE SHOWING POURING SPOUT, POSITION OF TRUNNIONS AND AIR COOLING PIPE FOR COOLING TRANSFORMERS

a horizontal position either automatically or by hand. The furnace is rocked by means of motor driven gears meshing with a geared band around the circumference of each end of the furnace, the furnace being oscillated thereby through a variable arc. When ready to pour, the furnace may be tilted sufficiently to run the

metal through the spouted vent into a ladle; or a tilting around the spout device may be employed for pouring directly into molds. The furnace, as shown in the cross section view was lined by placing asbestos paper next to the shell with subsequent courses of sil-o-cel and fire brick. Within the last year and a half the sil-o-cel course has been eliminated, the lining consisting of only two courses. The furnace lined with refractory is then air dried, heated internally by means of a charcoal fire laid inside the lining and finally, by means of heat generated through the arcing of the electrodes until the temperature attained is high enough to allow starting.

Induction Type Furnace

The induction furnace used was of the Ajax Wyatt type. It consists of a metal shell having a cylindrical top chamber resting on a V-shaped bottom part containing the channel of molten metal. In the bottom of the V-shaped part of the furnace midway between the V-shaped channel runs a cylindrical opening which contains the copper coil or primary part of the transformer unit which in turn surrounds one leg of the laminated iron core. The channel, or duct, containing the molten metal ring, in which the heat is generated by an induced current to form the secondary part, runs from an opening in the floor of the top chamber down through and following the contour of the V-bottom to re-enter the floor of the top chamber through a hole similar to that first mentioned, thus forming an unbroken molten metal ring from the back to the molten bath in the chamber proper.

The assembled shell is supported as shown on trunnions. In the upper back part of the shell is located a rectangular-shaped opening for charging. Directly opposite in the front part, is located the pouring spout.

The furnace is tilted by means of a "cartwheel" type of turning handle connected through gears and worm to a pulley and chain attached to a sheave, which tilts the furnace to the position desired.

The furnace is lined by first placing asbestos paper next to the shell, then a layer of sil-o-cel brick or similar insulating mate-

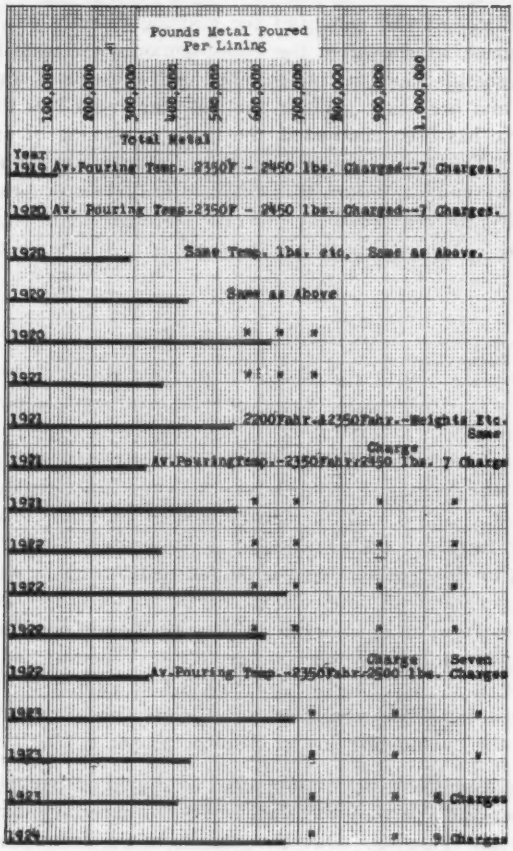

FIG. 5—CHART SHOWING FACTORS OF LIFE OF LINING

rial against which the refractory cement is tamped and rammed around prepared forms in successive stages until the V-shaped bottom and cylindrical shells are completely filled with rammed-in refractory. The forms are clamped in place to secure the proper size and shape of channel, forming the secondary part of the cir-

cuit, the opening for the transformer coil, and the chamber. This type of furnace is shown assembled in the illustration, an inspection of which will give an idea of the shape and relative size of parts.

Refractory Problems of the Rocking Arc Furnace

In the use of the rocking arc type of furnace, it has been our practise to employ a one-ton furnace for melting a charge of metal weighing 2,500 pounds. The cast billets contain a high percentage of copper and a nominal amount of tin, and are poured directly from the shell into the molds. The refractory problem with which we have had to deal, for the most part, has been the failure of the refractory bushing by which the carbon electrode is held in the shell wall. This bushing, if allowed to spall and soften for any length of time will hasten the failure of the surrounding refractory lining with a consequent complete fusion and disintegration before any great amount of metal has been produced. If given immediate attention, by replacing the bushing bricks, softening or spalling in the wall, may be checked. Inasmuch as the above repair work requires interruption of production, it is often allowed to proceed to the extent that a general patching is necessary. It has been our experience that two replacements on refractory bushings and two general patchings of the entire lining have been required before completely scrapping a lining. While not so serious as the above and more easily handled, has been the failure of the door bricks, two sets of which have as a rule been required during the average life of a lining. Fig. 5 is a chart showing the life of some of these linings with the average temperature of pour, weight of pour, and number of pours per day.

Preheating Important

From the results just previously shown on the curve, it is obvious that we have had our good and bad linings with plenty of opportunity for increasing the length of life on this particular size of furnace in which a copper-rich, copper-tin alloy is melted. It has been our experience that very careful attention is required in the building up of the lining and preheating, before starting with the metal charge. Several days of preheating by means of a charcoal fire before introducing the arc heating are necessary for a suc-

cessful start. During the past few months, graduated heating between the charcoal fire and the starting of the arc has been carried on by means of an oil torch, starting with a moderate temperature and gradually increasing until ready for arcing the electrodes. Better results seem to have been obtained.

Refractory Problems of the Induction Type Furnace

Concerning refractory linings in the induction type of electric furnace, our experience has been entirely with the Ajax-Wyatt type, although some experimental work has been done on another type of induction furnace. In lining the V-type of induction furnace until recently, the refractory has always been rammed in, starting with a thin asbestos paper laid against the bottom or V-part of the shell against which the sil-o-cel or nonpareil bricks have been laid, the long side of the bricks being laid vertically against the paper.

The insulating bricks are laid in sections around and against which thoroughly mixed refractory lining material is tamped and then rammed down with a final rough finish for the succeeding layer of lining material. With the transformer bushing and duct forms held in place securely by braces, the material is rammed in until the furnace has been completed.

Quite recently it was discovered that the insulating brick used had a fairly high shrinkage value, and, having this property under high temperatures, it was thought that the shrinkage of the insulating brick was a considerable factor in causing strain cracks to originate in the rammed lining. Consequently, a "fire backing" with a minimum shrinkage was obtained and substituted. Due to the fact that it is impossible to observe what really takes place within the furnace lining material, it could not be determined that the substitution of this "fire backing" for insulating brick resulted in any direct improvement, but it was thought to be a safeguard against strain cracks due to shrinkage of backing material and therefore adopted. A cross section view of this lining is shown in Fig. 6.

Various methods of setting, air drying and preheating prior to the introduction of molten metal for starting have been tried.

The methods differ for different types of linings and will be so dealt with in the presentation of the problem according to the type of material under discussion. In the following paragraphs will be discussed the use of some different refractory materials and the results obtained.

Alumina-Silica Refractory Linings

The use of alumina-silica refractory cement containing asbestos fibre was coincident with the introduction of the furnace. In its use in furnaces melting yellow brass both good and bad linings resulted. Averaging the periods of lining life, however, it may be safely stated that an alumina-silica refractory cement fus-

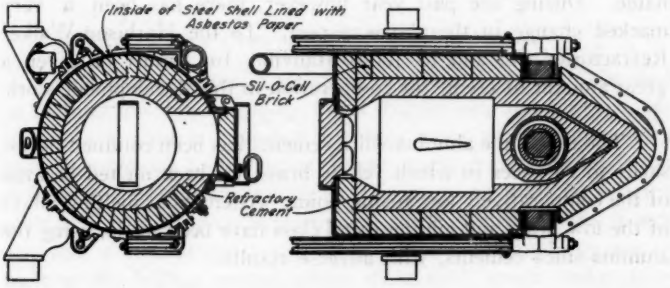

FIG. 6—CROSS SECTION VIEW OF INDUCTION FURNACE SHOWING POSITION OF RAMMED PARTS. RECENTLY FIRE BACKING HAS BEEN SUBSTITUTED IN PLACE OF SIL-O-CEL BRICK

ing about 2600 degrees Fahr. will give fairly satisfactory results on brass, if properly sized and thoroughly mixed in its manufacture. Consistently uniform chemical composition, texture, and size of grain must be maintained as a basis for the preparation of a satisfactory refractory cement. Because of variations in the above properties, a second source of essentially the same type of cement was tried and while the period, over which this cement has been used in furnaces melting yellow brass, has been comparatively short, more consistent lining life seems to have been obtained, chiefly due to the general uniformity of the cement.

Up to a year ago, one of the problems with which the operator of the induction furnace had been confronted in securing a satisfactory refractory, was the difficulty in obtaining from some refractory cement manufacturers definite specifications covering chemical composition, texture, size of grain, etc., which would form the basis of specifications for use when ordering the cement. There seemed to be a tendency on the part of the manufacturer to study superficially the operators requirements and then to attach to a product developed for the operator a trade name, by which the material had to be ordered, subsequent lots of which departed from the original in some of the essentials. This condition forced the furnace operator to take up the study of refractories in order that he might protect himself by intelligent purchase of material rather than promiscuous buying by trade name. During the past year however, there has been a very marked change in the above respect. To the Harbison-Walker Refractories Co. and to Johns-Manville, Inc., must be given a great amount of credit for co-operation in this development work.

The use of the alumina-silica cements has been confined necessarily to furnaces in which yellow brass has been melted because of the comparatively low fusing point. Attempts at melting alloys of the low brass and gilding metal class have been made, using the alumina-silica cements, with adverse results.

Even in the melting of yellow brass mixtures in furnaces using alumina-silica cement as the refractory, it has been found necessary to take precautionary measures to prolong the life of the linings. "Driving" the duct, during operation of the furnace and cleansing the encrusted refractory by means of molten copper, have been measures to which the operator has had to resort. "Driving" consists in forcing a steel bar down each side of the "V" to the point, breaking off the encrusted material to prevent the furnace from ceasing to operate. The addition of molten copper will scour the lining around the metal ring very often so that efficient operation may be continued.

The most familiar reason for causing a furnace to "break down" in operation is the short circuiting of the primary and sec-

ondary system by means of a connection of the molten ring with the primary coil. This failure is due, usually, to a crack existing in the refractory through which the molten metal filters until a contact between the molten ring and the primary coil is formed.

The "freezing" or solidifying of the molten ring has been an all too frequent cause of failure and is usually started by a gradual reduction in the area of the metal ring due to encrustation of dirt, zinc oxide, and some fused matter to the point where neglect temporarily allows the metal in the ring to "freeze" or become mushy. However, it has been the experience of electric furnace operators in our plant that an alumina-silica refractory cement with no wide variations from the standard in chemical composition, grain size, and texture, will give very satisfactory results in melting yellow brass alloys.

Refractory Cements for High Copper Alloys

Since no consistently satisfactory results have been obtained in melting low brass, gilding metal, copper-tin, and pure copper mixtures in electric induction furnaces using an aluminum-silica cement, previous to our co-operative work, it was decided that refractory cements having higher fusing points must be selected with which to carry on experimental work. Furthermore, it was felt that a cement satisfying the conditions required for use in melting the higher copper alloys mentioned would make more efficient in operation those furnaces melting yellow brass alloy and prolong the life of the latter furnaces considerably.

Coincident with this decision a change in the attitude of the refractory cement manufacturers was noticed. Furthermore, it is worth noting that two of our leading refractory cement manufacturers recommended at this time a type of refractory cement essentially the same in composition. This cement contains as a refractory, a chrome ore fairly low in silica content. The recommendation that a chrome base cement instead of an alumina or magnesia base be used, was made because of the comparative ease in bonding the chrome base cement.

A great amount of time was first spent in the development of the proportions of refractory and bond and in the sizing of the re-

fractory materials to be used. In the case of the first source a satisfactory cement for ramming and bonding seemed to have been obtained and then, later, difficulty was experienced in ramming and bonding the cement, so that it is only with the second source of cement that the balance of this paper has to deal.

As a conclusion to the preliminary work with one of the manufacturers mentioned above, six cements of varying composition were selected with which to carry on further experimental work to determine which one or more would give satisfactory results. Elaborate tests on shrinkage, expansion, vitrifaction, and fusion have been carried on to the end that one cement has been selected which seems to give the best results. In this work, it must be remembered, the objective toward which all experimntal work has been directed, has been to obtain a refractory cement that will function properly at temperatures attendant upon the melting of alloys containing copper, in excess of 80 percent, combined with zinc; and alloys of tin and copper where the variation is from 1 percent to 8 percent tin. Supplementing the above, various cement mixtures have been found during the course of the experimental work which have permitted the operation of furnaces more efficiently and for longer periods before failure. This latter result has opened up to the cement producer a much wider field than formerly held inasmuch as very consistent results have been obtained with various mixtures of chrome base cements on melting alloys composed of copper and zinc as high as 95 percent copper and 5 percent zinc. Although some fair results have been obtained in melting phosphor bronze mixtures and phosphorized copper, the runs have not been so consistently satisfactory to warrant the conclusion that the problem has been solved.

Enough data from experiments on shrinkage, expansion, etc., from normal temperature (60 degrees Fahr. up to 2400 degrees Fahr.) have been recorded to permit the conclusion that a cement has been obtained which will give satisfactory results so far as the above properties are concerned. During the period of air drying, preliminary heating before priming, and actual priming, a sufficient number of observations have been obtained to warrant the conclusion that not very much is to be feared in the preliminary treatment before actual melting takes place. Indications

seem to point to the fact that it is only after vitrifaction takes place that the cracking trouble develops to the point where actual failures follow.

Conclusions

The progress of the work to date has brought those involved to the conclusion that the problem must be solved in one of two ways; namely, that a refractory must be used in which vitrifaction will not take place under the working temperatures involved, at least to such an extent that the cross section of the lining affected will crack throughout; or, two different layers of lining material must be used to accomplish the first mentioned result desired. It is quite possible that, before the actual reading of this paper, the accomplishment of this end will be a fact.

The Temperature Determination of Non-Ferrous Alloys

By R. L. BINNEY*, Toledo, O.

In recent years the casters of the non-ferrous alloys have come to realize more and more the importance of casting their metal at the proper temperatures. For a long time the only pyrometer in the foundry was the eye of the foundryman. Many old timers felt that they had an infallible gift and could accurately judge the temperatures. Many of these men valiantly fought for their principles and made it very difficult for the technical men to supplant the former methods with instruments. If the losses incurred by faulty casting temperatures could be calculated, the amount would undoubtedly be very large.

There is probably no question arising in the non-ferrous foundry that is more difficult to solve properly than that of temperature measurement. Many of the instruments will give a series of readings varying from 20 to 150 degrees in the same pot of metal. The causes for these variations in readings will be explained with reference to each method. The workers who have not spent considerable time on this are often deceived, and when they realize this, they have no further use for the apparatus. It is not a simple question, but a very difficult one and is beset with many catches which, to many, have proved very discouraging.

The writer has been studying this question for the past six years. Prior to this time his work in temperature determination had been in the glass and steel fields. After becoming thoroughly convinced that the correct solution was of enormous value, various types of instruments were carefully studied over long periods, the literature investigated and many conferences held with coworkers in a similar business.

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The devices investigated were:

Optical Pyrometers
Radiation Pyrometers
Temperature Cones
Base Metal Pyrometers
(a) In protecting tubes
(b) For direct immersion
Rare Metal Couples—Protected
Potentiometer vs. high and low resistance meters
Combination of methods.

Various makes of the same device were tried and the discussion does not refer specifically to any one make. All of the pyrometers have their good as well as bad features and this paper does not condemn any one make. It is, in fact, a discussion of the temperature determination of non-ferrous alloys with melting points from 1800 to 2500 degrees Fahr. It must be said in justice, that several of the makers of our best standard instruments told us point blank that they had no equipment giving the necessary accuracy and did not recommend their equipment for this special problem. They were urged to develop some satisfactory outfit but evidently the commercial pressure for this particular field had not reached a sufficient magnitude to warrant their spending time and money.

Optical Pyrometer

It was decided that if the optical pyrometer would prove satisfactory, it would present several marked advantages because there would be no thermocouples to renew, and the attention necessary would be relatively small. It was attempted to sight the instrument directly on the molten metal but this was not satisfactory, not only because there is not the black body condition but also because the surface may be covered with a thin film of slag or because the rapidly forming oxide on the surface causes false readings. A black body (graphite) was next introduced and the instrument sighted on it, but with no success. The body had to be kept at high temperature so that no time was lost in determining the reading. As the metal was poured from the furnace, slag got on the body or it crumbled or broke.

It was then attempted to fasten a graphite tube at the end of a rod with a telescope of the pyrometer fastened at the other end of it so that they were in alignment, and it would only be necessary to look through the telescope to sight directly into the tube. The tubes were to be immersed in the molten bronze to approximately the center of the pot. This was calculated to give the real temperature and not the surface reading. For a time it seemed that the method was a success but the tubes are fragile and the outfit as a whole did not seem rugged enough for foundry service and was eventually abandoned. In order to get accurate readings it was necessary to maintain a high class man, as the ordinary foundry workman failed to balance the indicator.

Radiation Pyrometer

A radiation pyrometer was tried and its arguments appeared to be attractive. In this case the furnace operator did not have to balance the instrument but merely point the tube at the bronze and read the temperature direct. This instrument also possessed the attractive feature that there would be no thermocouples to renew and, being light, the portable apparatus appeared very convenient. Of course the instrument was unable to give correct readings or even relative ones because of the body and surface conditions of the metal. So after careful trial this one was abandoned.

Seger Cones

In order to extend the field an entirely different principle was employed. Seger cones were introduced into the furnace by standing them on a floating body. It was thought by some that the method would be close enough but the results were of course worthless. Since the softening point of Seger cones depends on the nature of the atmosphere and especially upon the time and on the rate of heating, it is readily seen that the method would be most difficult to develop for practical foundry purposes.

Base Metal Couples

Several makes of instruments employing base metal couples in protecting tubes were tried. Here the temperature may be read direct and the surface conditions caused no difficulty. The

tube is immersed in the molten metal and a fairly correct temperature may be read. This, then, would appear a proper solution, but after two years this method was thrown out because of the many difficulties. In the first place the couples or rather the tubes must be kept at a high temperature in a special furnace or else the lag is too great for production work. If the tube be immersed in the metal from a fairly cold state, it takes several minutes to bring the temperature of the couple to that of the metal. This of course is impractical because of the loss of time and also because of the loss of heat, as the metal at the high temperature of molten bronze loses heat rapidly upon standing a few minutes and it is very undesirable to overheat the metal with an idea of compensating for the loss of the heat. A marked objection to this method is the fact the protecting tubes do not last long enough. The corrosive action of molten bronze is very great and the tubes rapidly burn through. As soon as the metal penetrates to the thermocouple a new protecting tube must be put on which is considerable work. It is often necessary to break off the protecting tube with a sledge, and then a new thermocouple must again be insulated and the old one welded. After five years of effort, we gave up looking for a protecting tube that would last long enough to warrant its use. Composition tubes (not metallic) were also tried but they were not satisfactory. Altogether the method proved not only troublesome but expensive.

It was next decided to try unprotected base metal couples. Several makes of instruments were tried as well as for the other methods discussed. Here you have the advantage of an immediate reading and it is not necessary to preheat the couple. Great care must be used to remove all slag from the surface and have it absolutely clear when the wires are immersed. Temperature determined in this way is the surface one and the metal must be thoroughly poled just before the reading is taken. In all cases there are certain difficulties which appear to the layman as easy of correction but there are, regardless of the assurances of the manufacturers, many minor troubles that vitiate the readings. The connections are always coming loose or the leads break or dirt gets into the contacts. We have tried every conceivable form of connection and have employed armored cable, but so far there has

been no really liable connection. The cold junction must be brought to the meter and the temperature of the member known, for in the foundry the meter is sometimes quite warm and again it is cold. The direct immersion method when carefully applied can give good results, but it is very easy to have two different workmen get readings varying by 100 degrees Fahr. A little surface slag will often cause a great deal of trouble. Another point against this method is that the couples burn off so rapidly and that the upkeep is high.

In all cases where thermocouples and meters were used, a method of checking was employed each day. The thermocouples are checked against a standard and the meters are checked by means of a potentiometer. It is not safe to take a chance and imagine the instrument as always correct. Sometimes it seemed as though the checking was not necessary but ever so often, we found the meters indicate false readings and have decided that the checking system is very essential.

Rare Metal Couples

After constant effort to overcome the trouble of determining casting temperatures, it was finally decided for furnaces other than the crucible type that some permanent installation of a rare metal couple would be of assistance. With the crucible furnace, it is possible to use a base metal couple with a protecting sheath because here the lag that is experienced in the determination of the temperature of the metal poured from a furnace is of no importance. With the larger types of furnaces, it is of marked advantage to know the temperature before the furnace has been opened. If the temperature of the metal is known as it is being brought up to heat, there is no danger of soaking it or overheating it. This not only is an advantage from a purely metallurgical viewpoint but it is likewise a saver of time and fuel. In order to accomplish this, platinum couples were embedded in the roof of the furnace and the attempt was made to find a relative value between the temperature of the metal as poured from the furnace and that indicated by the platinum couple just prior to the opening of it. Since there was a large battery of furnaces to deal with, it was attempted to have this factor the same in each case. The rare

metal couples were embedded in porcelain tubes which were in turn placed in other protecting tubes, the end of which was exposed to the furnace atmosphere. The idea was to get the differential between the reading obtained by this arrangement and that obtained by immersing a couple directly in the metal. For instance, a certain furnace would give a temperature of 1500 degrees when the metal showed 2000.

It was a good idea and was partially successful but after considerable work it was decided that if the couples were embedded in the bottom of the furnace the results would be more accurate. When the door was opened the chilling effect, which was found detrimental to the atmospheric determination, would not be noticeable if the temperature was gauged from the bottom. This method is a very good one but routine control must be strictly enforced or the workmen will vitiate its virtues. In other words, if the temperature is determined, it is done so with the idea that a certain length of time elapses from the time the temperature is taken until the metal is in the pouring pot. If there are too many delays, it reduces the system to the evils of too much guesswork.

Potentiometer vs. High and Low Resistance Meters

It might be well to consider the different types of instruments keeping in mind the operating conditions. The meter must be rugged, accurate and easily read. The high resistance meter is accurate and the variations in the external resistance are not so detrimental but against these points there is the delicate mechanism which constantly gets out of order in general foundry practice. We were never able to use this type meter except when it was fastened on a rigid support. This is a disadvantage as the metal must be brought to it. The low resistance meter is more rugged and when rigid stands are placed at convenient places, may be handled with safety in a foundry. This type of meter has the disadvantage that changes in the external resistance vitiate its readings and since it is necessary to change cables, this point must be watched. We had two cables (wires that connect thermopoints with meter) from the same company about the same length that gave readings differing by 80 degrees Fahr. We also found that the socket plugs used to connect the cables afforded varying resist-

ance. When the external circuit does not vary in resistance, the low resistance meter does fairly well because it can be handled with less care, however both types have their disadvantages. The potentiometer has the advantage that the resistance of the circuit will not effect the reading. An automatic compensating potentiometer in most respects is superior to either type of meter. The greatest difficulty we have with this instrument is to quickly and correctly balance the galvanometer. The fact that it is independent of the resistance makes it possible to have one instrument with leads of varying length, hence one meter may be rigidly installed in a suitable location and connections made with various points in the foundry. This has the disadvantage of requiring two men if bare couples are used. We do not find it practical to move the potentiometer about, hence the single station idea.

Combination of Methods

There are two times at which a knowledge of the temperature is important and a double system using two different methods applies. As soon as the metal in the furnace has reached the correct temperature, it should be poured as it is detrimental to the metal to soak in the furnace and costly in time and fuel to keep the furnace going after the pouring temperature is reached. The metal should be cast at a certain temperature depending on size and shape of casting, length and section of runner, etc., as this temperature affects the physical properties. To gauge the temperature in the furnace, platinum couples are imbedded in the bottom and are connected to a central potentiometer station and to determine the casting temperature, an unprotected base metal couple attached to a portable meter is used. These two systems are a check on each other and of real value, however we are still looking for a more reliable and simpler method.

WRITTEN DISCUSSION

G. Jensen, General Engineer, Inspection and Testing Dept., Westinghouse Electric and Mfg. Corp., E. Pittsburgh, Pa.

The thermocouple has been accepted, generally, as the most reliable means of measuring the temperature of molten non-ferrous alloys. Whether the electromotive force set-up in the ther-

mocouple is measured by a potentiometer or a millivoltmeter is of little importance, relatively, and certainly is not the problem. The problem has been and still is one of thermocouple design and construction.

Protection for thermocouples practically has been abandoned owing to the time lag introduced, and as a result the problem, fundamentally, has been reduced to one of kind and size of thermocouple wires. Related to this is, of course the question of whether the wires should be joined, which in turn is determined largely by the size.

As indicated by Mr. Binney an unprotected thermocouple will give erroneous results if the active end is not kept free from slag or other foreign matter. This error may be even larger if the thermocouple wires are not connected together, owing to the possibility of a high electrical resistance existing between the wires. This is true especially if a low resistance instrument is used for measuring the electromotive force.

It is the writer's experience that the thermocouple wires should be small enough to permit of twisting together easily, and that a new twist should be made after each temperature determination. Using small thermocouple wires not only reduces the time lag but also practically eliminates errors due to slag accumulation.

H. F. Seifert, Assistant Superintendent, Brass Foundry, Westinghouse Electric and Mfg. Corp., East Pittsburgh, Pa.

I can readily appreciate that the type of instrument would present quite a problem in a small organization in so far as the maintenance of the same is concerned. For us in the electrical business this is not such a serious problem. As Mr. Jensen states, the protection for thermocouples has been practically abandoned. We have had very good success with the base metal thermocouple for direct immersion but I have often wondered myself whether or not we had the right size of wire for best results. I thought at one time that we ought to use heavier wires but other difficulties enter in that make this questionable. I am speaking right now only of the measurement of temperatures for bronzes where the wire is rather rapidly consumed. White metals present an en-

tirely different problem, in fact, I have come to the conclusion that every alloy or group of alloys presents a special problem.

For the bearing bronzes we have found the base metal thermocouple as above mentioned very satisfactory. For the high tin bronzes it does not answer at all and we have found no satisfactory means of measuring temperatures of these alloys. Copper we pour as hot as we can get it, finding that the hotter the metal is the better is the shrinkage and freedom from blowholes. On white metals we use the open end base metal thermocouple with rather a heavy wire and find it very satisfactory. On the whole I think we have taken a decided step forward in temperature measurements in the last five years and we are making use of the developments as they come up. I am not prepared to say that we have reached the goal but the results we obtain today are much better than what we had several years ago.

DISCUSSION

H. M. St. John: I do not believe it is possible to get any two people at this stage of the game to agree as to methods of measuring. I think we are all agreed as to the importance and connection between temperature control and quality of casting. Our experience doesn't check either with Mr. Binney's experience or that given in the discussion printed with the paper, that is, the experience on my own part and quite a little experience in the foundry where I am now.

We have settled upon the use of the open end base metal couple, one-quarter inch in diameter, and the other one-eighth. We use a low resistance meter and don't have any particular trouble with our connection between the meter and the stick. I don't see why that should be known as trouble. We do find, however, that taking the temperature of the surface of the metal is not satisfactory. We can't get consistent results from one part of the metal to the another. In order to avoid that trouble, we found that if the tips of the couple are dipped about 3 inches below the surface of the metal and then the reading of the meter is allowed to come to approximately a steady point at which time the meter is registering the surface temperature but the tip reading is of a higher temperature not showing up on the meter, then the tips are drawn so that they are just immersed in the metal. When that is done, the needle on the meter will tip upward forty or fifty degrees and momentarily you are getting the reading that corresponds to the temperature, 3 inches below the surface. Take for instance the part of metal that is 2250 degrees inside, not on the surface but below the surface. When the

tips are dipped, the meter will come up to a reading around 2200 degrees. When the tips are lifted that will jump to 2250 degrees. We have found in that way you can get very, very successful results. It seems to be much superior in our experience than depending on the surface temperature.

We find the whole temperature on the various kinds of castings to vary plus or minus ten degrees. We attach a great deal of importance to this fact. On our meters we take about 400 readings a day and find the elements last 100 readings per pair, at an average temperature around 2250 for the reading. The meters are checked every day. We have three or four meters and some forty-five sticks and we check them that way. While we do have some difficulty, still it is not particularly serious.

It is important, as Mr. Binney says, to have the surface of the metal clean. We aren't all letter perfect on that and we get erratic readings. Erratic readings can be recognized because the action of the needle is so irregular and uncertain that a man with experience knows it is not a correct reading.

I don't believe that twisting the tips together is of any particular value, at least, it wouldn't be at the temperature we work. The wires would burn off before we could get a reading. It takes us around ten and fifteen seconds.

G. F. HUGHES: I would like to ask Mr. Binney if he has had any experience taking temperatures in any other way than crucible metal, such as in an induction type furnace?

R. L. BINNEY: We have tried for a long time to open the furnace and put the couple in the furnace before taking the metal out. Is that what you mean?

G. F. HUGHES: The idea of getting a temperature in the duct opposite the center of the transformer.

R. L. BINNEY: We do not use electric furnaces. All our experimenting was done in our own gas-fired furnace.

G. F. HUGHES: There has been a whole lot of controversy about that point.

D. WILLCOX: Dr. Northrup invented, ten years ago, a low resistance instrument which has the accuracy of a potentiometer. It is as rugged as a low resistance direct reading instrument. It can be read and checked against a small battery. It depends upon the permanent magnet in the instrument for its accuracy as to its potentiometric readings.

G. K. ELLIOTT: I would like to ask Mr. Hughes if he used the optical pyrometer.

G. F. HUGHES: The optical pyrometer wouldn't help us out there because in a furnace containing a full charge of metal, you are at least fifteen or sixteen inches below the surface of the metal and the particular point at which we want to get is that point within the belly of the duct

G. K. ELLIOTT: I had in mind some experience along the line of that mentioned by Mr. Binney. We found it of most advantage in reading the temperature in the furnace. The charges run from 1200 to 2000 pounds, that is, an oil air type of furnace, hollow cylinder, and I found out the opticals worked pretty well. Just before we took the reading, we shut down the furnace and for an instant put on a blast to blow out the fume and get, for a few seconds, a very clear atmosphere. It gave a black body condition inside the furnace and we found by checking against thermocouples, we got quite accurate readings. I thought that might have some bearing upon the problem you had in mind.

R. L. BINNEY: When we had the meter, not the potentiometer, we used to check the meter against the pyrometer in one part of the check. Then we had a standard thermocouple that we connected to the meter after we had checked it, and we inserted that in the furnace. We got the reading of this last and compared with the others.

G. H. CLAMER: Quite a number of years ago when we were experimenting with types of furnaces, Dr. Gillette, used a pyrometer he was working with at that time. I am not quite sure of the construction of the pyrometer. He inserted the point some distance in the ducts and took some determinations there and also some determinations on the surface of the bath. He found a difference of only 20 degrees between the temperature of the metal, probably six or eight inches below the surface, as compared with the surface temperature.

G. F. HUGHES: That corresponds exactly with the experience we had and we were wondering whether we were off our track there or if that was true. We found a difference of 50 degrees between the surface and that point. Our experience in the refractories end led us to believe that possibly we were in error.

G. H. CLAMER: The difference in temperature is the function of the furnace conditions and the dimensions of the duct and the amount of power you put in. In that particular furnace which had large ducts, there was only 20 degrees difference.

Atomized Coal System of Non-Ferrous Melting

By R. BLACK* AND C. L. SHAFER,* Cincinnati, O.

The atomized coal system is a name applied to the use of specially prepared bituminous coal for melting non-ferrous metals. The experience had to date has been confined to the crucible type of furnace. The coal is treated so as to reduce it to an impalpable powder resembling flour in texture. The coal so treated is called atomized coal. The reduction of coal to a powdered form is well known, and its use for industrial heat is well established. A good survey of the field can be found in Bulletin No. 217, U. S. Bureau of Mines.

We distinguish atomized coal from powdered coal as powdered coal is practically standardized to have 75 per cent pass a screen of 200 openings to the lineal inch and all of it pass a screen of 80 openings to the lineal inch, while atomized coal must all pass through a 200 mesh screen and contain grains of further diminishing sizes to the infinitely small. That this difference is substantial is shown by our experience that it is not practical to maintain a fire with powdered coal in the standard crucible furnace, although we have been very successful in this respect with atomized coal.

Preparation

Atomized coal is prepared in a succession of steps from nut and slack bituminous coal. It is first passed through a crusher reducing the whole volume to not exceeding the size of wheat grains: then it is passed through a drier to remove moisture. It is an essential part of the process that the coal must be rendered bone dry so far as it is commercially practicable. From the drier it is then passed through an atomizer which is a tumbling rod mill into which the coal is fed by a screw conveyor through the

*Gibraltar Bronze Co.

axle of the mill and in which the coal is kept in agitation by an air blast. The drier has a function of not only removing the moisture but of dissipating the methane gas held between the coal layers. The dissipation of the methane gas has the result of rendering the final product non-explosive within practical commercial limits. In the atomizers, the coal has become atomized coal and it is removed by a suction fan while suspended in air. The coal laden air is conducted into dust collectors from which the fuel drops into strong paper sacks for convenient handling.

Burning the Atomized Coal

The sacks will contain a fluffy mass of coal flour that will require special apparatus to feed it into the place of combustion with the proper amount of combustion air.

This is accomplished by a machine called a carburetor, consisting primarily of a storage tank, a revolving disk and a motor driven fan. The motor driving the fan, which is housed in an aluminum shell, also drives the revolving disk at a rate of 18 revolutions per minute. The disk constitutes the bottom of the storage tank which is a cylinder of galvanized iron with a capacity of 300 pounds of coal. Mounted on the disk is a cone with projecting arms which at once supports the mass and agitates it to overcome packing or lodging. As the disk revolves, a tangentially placed knife cuts and scrapes off a variable amount of coal controlled by adjusting the angle of the knife. This coal drops off the knife into the fan opening which blows a mixture of coal laden air through a pipe into the furnace. In the foundry of The Gibraltar Bronze Company two furnaces are connected to one carburetor by a "Y" pipe with valves so that either one or both may be operated. In experiments as many as four furnaces have been connected to one carburetor, but we believe the most satisfactory control can be obtained by not exceeding two furnaces for a carburetor. There is a shutter control for air built in the blower so as the supply of coal is varied the air can be adjusted in compensation. We redesigned the carburetor ourselves and the moving parts consist of the disk, two gears and a worm drive. It occupies a space 3 feet in diameter by 5 feet in height and weighs 350 pounds.

Theory of Practice

The theory of practice that has been heretofore worked out for the air requirements in the combustion of powdered coal of the standard type do not hold good with atomized coal. We have steadily diminished the air supply and combustion space with a correspondent increase in efficiency and economy of coal. The coal laden air as mixed and blown into the furnace is under a pressure of three ounces to the inch or just about sufficient to move the coal, suspended in air, into the furnace. This has the effect of preventing any excess of oxygen and in conjunction with the restricted combustion space of producing a strictly reducing atmosphere so that losses from oxidation are negligible.

Type of Furnace Used

The furnace used is the standard crucible furnace consisting of an iron shell lined with a refractory and covered with a refractory lid with a four inch orifice directly over the crucible. A collapsible stack is erected over the furnace so that it may be drawn down closely to the lid while firing and elevated to permit withdrawal of the charge. While firing with the stack drawn down the escape for the products of combustion is directly over the crucible with the result that the non-combustible content of the coal is melted and deposited as slag upon the surface of the charge. This slag acts as an impenetrable seal effectively closing the content of the charge and so limiting losses by oxidation and by the absorption of gases or other impurity. The slag also acts as a flux and assists in the cleansing of the metal. It readily comes off with a skimmer after drawing the crucible. The pipe conveying the coal laden air enters the furnace through a vertical slit in the side of the furnace to enter which the pipe is flattened to a hognose. The pipe is so arranged that the coal laden air enters the furnace tangentially, giving a whirling motion to the flame around the crucible and ascending to the opening over the crucible.

Our experience has been in aluminum, brass and bronze with very satisfactory results. In melting red brass, the amount of

fuel varies with the required heat to the charge and the cost of melting varies in proportion. Thin castings take a greater heat and more coal. Chunky pieces of relatively large size are, of course, poured at a less cost. The largest piece cast by us was 450 pounds. To work out the costs of melting, the cost of fuel

Cost of Atomizing Coal

Atomized coal has not as yet been manufactured upon a commercial scale so that the proportion of overhead and fixed charges per ton has been relatively high. The cost of material, process and sacking is about $4.85 per ton. The plant investment for preparation is about $125,000.00. A charge for capital, interest and depreciation, administration and sales has raised the cost on a small production to $8.00 per ton, which with freight, has made the cost to us $12.00 per ton. The fuel comes in stout paper sacks averaging 40 pounds to a sack about the size of a cement sack. It is shipped in box cars to protect it from weather and has a freight classification as a manufactured product much higher than raw coal.

Cost of Melting

At $12.00 per ton, the cost is .6 of a cent per pound. We will run three pounds of very hot metal per pound of coal at a cost of 2 mills per pound and six pounds of metal per pound of coal for very heavy chunky castings at a cost of one mill per pound. Our average experience with medium small castings is four pounds of metal are melted per pound of coal at a cost of one and one-half mills per pound of metal melted. This is our red brass and bronze experience. With aluminum our cost is much lower, but we have not made sufficient measured tests to give precise figures.

We believe this cost of melting, as given, is considerably lower than other available fuels used in crucible processes, but such saving in cost is a small factor in estimating the worth of this process. We find the life of our crucibles to be prolonged 200 per cent. We use a crucible to between 130 and 140 heats with red brass and find it to be still serviceable for aluminum.

We have used the same furnace lids for ten months and renew the furnace lining at intervals of six months. This is accomplished through the protective coating of slag from the melting of ash content of the coal and the maintaining of a reducing atmosphere of carbon monoxide in the combustion chamber. Our loss by oxidation of metal does not amount to over half of one per cent, as it is protected by the atmosphere and by the deposit of slag on top of the charge.

We have had an experience of an extraordinary low loss in defects. We have had only one experience of porous metal in castings and that we ascribe to the ingots in that instance being burnt by the smelter. We have sold about $15,000.00 worth of castings of all descriptions in ten months operation, most of which were machined and while we had returns because of defects in molding and rejects because of misruns, we believe our experience justifies the statement that the process practically eliminates porosity. About one-third of our sales have been aluminum, and we have never had an aluminum casting returned.

Our customers assure us that our metal has a greater density than metal obtained from other sources. We are told that it wears longer in bearings, and that in cutting, the turnings curl without cracking. We have been, therefore, able to maintain our prices over the current local market.

Burning Installation

The installation is not costly. Twelve hundred dollars would roughly represent the investment in two furnaces, the carburetor that supplies both and the stack. The power demand is to supply a one horse power motor mounted on the carburetor. The operation is very simple and without trouble. With the exception o the disk, all moving parts are enclosed in a dust-proof housing and run in grease. The fire is started in a cold furnace with a piece of newspaper and a handful of sticks or a bundle of excelsior to supply the initial ignition. After it is started and the furnace heated, ignition is continued by the retained heat and the supply of coal may be reduced. The only care required, after starting, is to keep the storage tank replenished. The supply of

fuel is shut off entirely to withdraw a charge and ignition will take place after an interval of five minutes from the retained heat in the furnace. In a large operation, fuel may be supplied by gravity from an overhead bin, instead of filling the storage tank by hand to its capacity of three hundred pounds.

The furnace heats quickly. A two hundred pound charge of red brass in a cold furnace can be brought to a pouring temperature in forty-five minutes and the subsequent charges in thirty minutes. With aluminum the charge can be poured in twenty minutes, starting with a cold furnace.

The factors described produce a combustion that is the essential feature of the process. Perfect combustion does not take place until the chamber is heated. That takes three to four minutes, starting with a cold furnace. Then the volatile content of the fuel is changed to gas immediately upon entrance and burns as a gas with a flame beginning about one inch from the entrance. The fixed carbon is coked and burns as particles in suspension. The ash is melted and deposited as slag on the walls of the furnace, the exterior of the crucible and the surface of the charge. The accumulation of slag is not troublesome, as it is loose and friable and need only be removed once a week. After the chamber is fully heated, the visibility of the flame is greatly reduced and the whole interior becomes incandescent. The heat limit exceeds any requirement for commercial purposes and the temperature is readily reduced to the degree needed by restricting the supply of fuel.

The experiences recited have been had with atomized coal made from an inferior grade of coal, high in ash and sulphur and averaging 12,000 B.T.U.s. It is proposed to remove the mill from Evansville, Indiana, to Cincinnati, to make a high grade of coal available and we are confident that the change of fuel will further reduce the cost of the process. A volume production will also reduce the cost per ton.

We believe that the use of this fuel will become general in the metal industries and will mean an advance both in efficiency and economy.

WRITTEN DISCUSSION

F. L. WOLF,* and WM. ROMANOFF,** Mansfield, O.

After reading the paper on "Atomized Coal System of Non-Ferrous Melting," and comparing some of the statements with our experiences both in brass melting and in the use of powdered coal, we felt that there was such a divergence of opinion that it was worthy of discussion before this association.

We notice that the authors state that the main difference between atomized coal and powdered coal is the fact that in the former the coal must all pass through a 200 mesh screen while in the latter only 75 or 80 per cent must pass through a 200 mesh screen. When we first commenced melting with powdered coal, we passed 90 per cent through a 200 mesh screen and later reduced the fineness to from 70 to 75 per cent through a 200 mesh screen. This change caused no reduction in the time of melting nor in the pounds of metal melted per pound of coal. The secret of successful combustion is not so much in the fineness of the coal (within reasonable limits) as in the proper size of the firebox, temperature of firebox, volatile matter in coal and proper air ratio. We hardly feel that passing coal through a 200 mesh screen makes a "substantial" difference.

The authors in their paper also claim that the drier has a function of not only removing the moisture but of dissipating the methane gas held between the coal layers, and that this dissipation of the methane gas renders the final product non-explosive within practical commercial limits. We have frequently sampled the gases leaving our drier and the exhaust from our pulverizing mill but we have never found methane present. We do not, however, feel that our product is non-explosive. With further regards to the hazard of powdered or atomized coal, we quote below several excerpts from Bulletin 20, Bureau of Mines on the "Explosibility of Coal Dust." By coal dust, they mean coal that will pass through a 100 mesh screen.

On page 27 they advise that "all finely divided carbonaceous material would explode."

*, **Technical Superintendent and Metallurgist, respectively, The Ohio Brass Co., Mansfield, Ohio.

On page 47 we find that the increasing order of inflammability is the same as the increasing percentage of volatile matter, while on page 91 they even go on to prove that the presence of inflammable gases are not necessary in causing an explosion of coal dust and air. From page 115, we quote as follows: "The acceptance of the theory has come about only through such large-scale experimental work, which has shown conclusively that coal dust alone may be the cause of serious disasters."

From the above excerpts, we, therefore, feel that the statement that atomized coal is non-explosive is rather ambiguous.

In regard to the reducing characteristic of an atomized coal flame as mentioned by the authors, they have disregarded the fact that in modern foundry practice this has been proven a detriment instead of an advantage. Numerous papers have been published in recent years to prove this fact. Trapped gases formed with a reducing flame often cause porous castings while the oxides formed through the use of an oxidizing flame can be eliminated by the addition of phosphor-copper or a similar deoxidizer.

The authors also mention the advantages of the slag formed by the settling of the ash on the surface of the metal. This slag may act as "an impenetrable seal effectively closing the content of the charge and so limiting losses by oxidation and absorption of gases or other impurities," but if it really does function in this manner, no more can be said. As far as acting as a flux and cleansing the metal, we cannot agree with the authors. In the melting of clean metals, the use of any flux is passe. In our foundry we have found after considerable experimental work that better castings can be obtained without the use of any flux. We have published the results in a paper* read before this Association at the Cleveland meeting in 1923.

The authors also claim that melting metal by the atomized coal process practically eliminates porosity. We do not intend to question the fact that "their metal has a greater density than metal obtained from other sources," but if this is the case, it is not due to the fuel. Other conditions probably enter in. In pres-

*Wolf and Romanoff, Trans, A. F. A., Vol. 31, pp. 355-365, 1924.

sure castings, improper pouring temperatures and improper gating are no doubt responsible for the largest percentage of porous castings. While good melting practice is essential, it is ridiculous to consider any fuel as a "cure-all" for porosity.

In conclusion, we might say that while the authors are to be commended for their work in pioneering a new fuel for the melting of non-ferrous metals, still we feel that nothing has been said or done to show the superiority of the atomized coal system of melting over that of the modern electric furnace, or for that matter, oil or gas melting. In fact, it has not even been proven the equal.

Handling Materials in a Brass Foundry

By T. C. Flinn,* East Cambridge, Mass.

The question of material handling first came to the writer's serious attention because of an article appearing in the April 23, 1925, issue of *The Iron Age*. In this article, the statement was made that sixty tons of material were handled to produce one ton of castings.

It was quite evident to the writer that the statement, as made by the speaker, was far from representing the true condition in the average foundry and our opinion was corroborated by an article printed in the April (1925) issue of *The Open Shop Review*. In that issue of *The Review* an article appeared entitled "Handling 168 tons for every ton produced." This wide divergence of opinion from two presumably reliable sources convinced the writer that perhaps the subject of material handling had never been given the careful consideration which its importance warrants. It is also interesting to note that the aforementioned article which appeared in the issue of *The Open Shop Review* also appeared in the same form in the April 15, 1921, issue of *The Foundry*.

Governed, at first, only by a desire to determine definitely for his own enlightenment the true answer to this important question, the writer made a personal check-up of material handling in a local brass foundry and also in an iron foundry operating under average conditions. The resulting figure of 152 tons for brass and 206 tons for iron handled to produce one ton tended to further corroborate the first opinion of the writer that the 168 tons mentioned came considerably nearer representing the true conditions.

Realizing that a subject where there is such a wide divergence of opinion has perhaps been neglected to some extent and that

*Foundry Engineer, Blake and Knowles Works, Worthington Pump and Machinery Corporation.

the importance of establishing certain standards as a basis for analysis would be sure to be realized by the foundry industries the writer made brief mention of these facts to the various trade journals and from the response which he received it is quite evident that the subject of material handling is due for considerable discussion.

The analysis which follows is that of the materials handled in a brass foundry having a daily average output of 2,500 pounds of castings, which requires 152 tons of material handling to produce one ton of castings. The principles followed in making the analysis, although in this case applied directly to a brass foundry, could easily be modified to meet iron foundry conditions.

All operations in the following analysis of the handling of materials in a brass foundry start with the taking of raw materials from the storage bins of the foundry, and following the operations through the various departments and ending with the castings delivered in the shipping room ready for use of other departments or for customers.

All operations outside of the foundry have not been considered in this analysis. They would consist of the delivery of materials, coreboxes, patterns and flasks from the outside or other departments of the works.

The handling of materials, coreboxes, patterns, flasks, shovels and other equipment in the foundry is considered in this analysis which is made up in divisions generally classified by departments in the operation of a brass foundry.

The question of material handling in a brass foundry is of greater importance than many persons realize, primarily because of the close relation which material handling bears to the problem of the elimination of waste by the reduction of the amount of material handled to produce one ton of castings.

Melting Department

OPERATIONS	Weight in pounds
Metal and scrap taken from stock bins and weighed	4,700

Delivering metal and scrap to melting furnaces	4,700	
Charging metal and scrap into melting furnaces	4,700	
Pouring metal into ladles	4,700	
Pouring metal from ladles into molds or ingots	4,700	
Total metal handled—Melting Department		23,500

Coremaking Department

OPERATIONS	Weight in pounds	
Loading new sand, taken from bins, into mixer	850	
Loading old sand, taken from foundry, into mixer bin	850	
Shoveling old sand, from bin, into sand mixer	850	
Emptying sand from sand mixer	1,700	
Delivering mixed sand to core benches	1,700	
Shoveling sand into coreboxes	1,700	
Turning loaded coreboxes on plates	1,700	
Setting core plates into ovens	1,700	
Removing core plates from ovens	1,700	
Delivering core plates to finishing benches	1,700	
Removing cores from core plates	1,700	
Turning over cores for pasting and blacking	1,700	
Placing finished cores in storage	1,700	
Setting finished cores along side of molds	1,700	
Placing finished cores into molds	1,700	
Delivering refuse core sand outside for disposal	850	
Total Material Handled—Coremaking Department		23,800

Molding Department

OPERATIONS	Weight in pounds	
Loading new sand from bins and delivery to foundry	500	
Spreading new sand over foundry sand heaps	500	
Gathering and dumping old sand over floor heaps	14,000	

Mixing old and new sand three times for molding 43,500

To produce 2,500 pounds of castings daily requires 400 molds of 12 inches by 14 inches flask size. Each mold covers the following ing cycle in material handling.

Putting pattern plate on machine....	Lbs.	18
Placing drag flask on pattern plate....	"	27
Filling drag flask with sand.....	"	17
Peaning and strike-off sand.....	"	..
Placing bottom board	"	5
Squeeze	"	..
Rolling over drag flask.....	"	67
Removing pattern plate	"	18
Placing drag flask on floor.....	"	49
Placing pattern plate on machine.....	"	18
Placing cope flask on pattern plate...	"	27
Filling cope flask with sand.....	"	17
Peaning and strike-off sand.....	"	..
Putting in cope board	"	5
Squeeze	"	..
Rolling over cope flask.....	"	67
Drawing off pattern plate	"	18
Placing cope flask on drag flask.....	"	44
Placing weight on mold	"	34
Material handled complete cycle for one mold	"	431
Material handled—400 molds (431 lbs. each)		172,400
Shaking out 400 molds—weight each 139 lbs..		55,600
Delivering refuse sand outside for disposal...		500
Total Material Handled—Molding Department		287,000

Cleaning Department

OPERATIONS	Weight in pounds	
Removing castings, sprues and gates to gangway	4,230	
Taking castings, sprues and gates to cleaning room	4,230	
Cutting sprues and gates from castings	4,230	
Delivering sprues and gates to metal stock room	1,600	
Moving castings and putting them in sand blast	2,630	
Removing castings from sand blast	2,630	
Grinding and chipping castings	2,580	
Inspecting and counting castings	2,580	
Loading castings for delivery	2,580	
Delivering good castings to shipping room	2,500	
Delivering all metal and grinding for recovery	110	
Total Material Handled—Cleaning Department		29,900

Miscellaneous Material Handling

(Not mentioned in the foregoing analysis)

OPERATIONS	Weight in pounds	
Equipment consisting of ladles, trucks, shovels, small tools, core boxes and plates	13,800	
Supplies, furnace linings, fluxes, core oils and sand blast sand and emery wheels	2,000	
Fuel oil used for melting and water used for foundry purposes not considered in material handling.		
Total Material Handled — Miscellaneous Materials		15,800

Summary of All Material Handled Daily Classified by Departments to Produce 2,500 Pounds of Castings

Department	Total Pounds Handled	Equiv. to to One Ton of Castings
Melting Department	23,500	9.40 Tons
Coremaking Department	23,800	9.52 "
Molding Department	287,000	114.80 "
Cleaning Department	29,900	11.96 "
Miscellaneous	15,800	6.32 "
Total	380,000	152.00 Tons

Summary of All Material Handled Daily Classified by Materials and Equipment to Produce 2,500 Pounds of Castings

Classification	Total Pounds Handled	Equiv. to One Ton of Castings
Metals	58,200	23.28
Sand	123,600	49.44
Supplies	2,000	.80
Equipment	196,200	78.48
Total	380,000	152.00

New High Frequency Induction Furnaces

By Dudley Wilcox,* Trenton, N. J.

The high frequency induction furnace described in this paper was developed in an effort to make the ideal brass melting furnace which was conceived to have the following characteristics:

1. The shape of the metal bath to approach that of a cylinder whose height is equal to its diameter because this shape has small radiating surface per unit volume.
2. Little or no waste space to be above the melt.
3. Aperture for charging to be large and easily accessible.
4. Pouring spout arranged so that molds can be poured from the furnace if desired.
5. Heat to be generated uniformly throughout the mass to be melted.
6. Thorough mixing of alloys without use of stirring rod or any motion of furnace.
7. Minimum refractory material to be heated.
8. Crucible removable for pouring if desired.
9. Standard shaped crucible to be used.
10. High efficiency.
11. High power factor and steady, well balanced polyphase load.

It was found that the use of high frequency current made attainable all of these advantages. The furnace for foundry use is designed as illustrated in Fig. 1 (cross sectional view of furnace). The metal is melted in a crucible surrounded by heat insulating material. The heat is applied by induction within the metal. The crucible requires no preheating.

There is no electrical connection between the crucible and the electrical circuit. The energy is supplied by electro-magnetic induction from a coil surrounding the crucible and separated from it by about one inch. Between the coil and the crucible there is a

*Ajax Electrothermic Corp.

heat insulating lining through which the electrical energy passes without in any way affecting the lining material.

The lining has small mass in which little heat is stored. The coil consumes but little power and is kept cool by means of a gentle air blast. The furnace is housed in a cylinder or box of non-conducting material such as asbestos board. Fig. 2 shows the furnace in melting position.

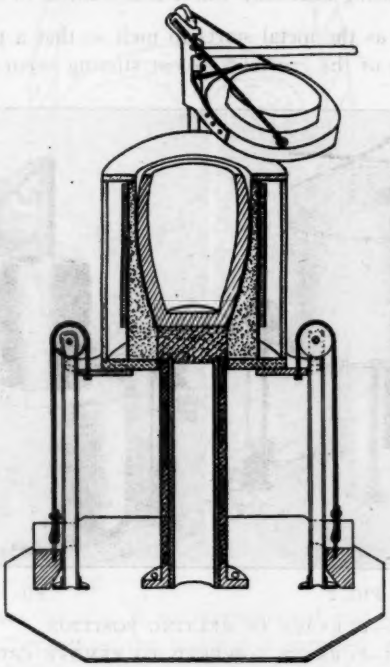

FIG. 1.—CROSS SECTION OF FURNACE

Operating

The metal is charged as in an ordinary fuel fired crucible furnace. There are no flames except what little may come off from oil or other matter on the scrap metal being melted. The outside of the furnace is at all times cool to the hand.

As shown in Fig. 3, the furnace housing may be lowered away from the crucible so that the crucible may be picked up with ordinary tongs and poured. Contrary to the usual condition the outside of the crucible is never heated hotter than the metal. This of course means that the crucible life is much longer than when the heat has to be passed through the crucible wall. Electromagnetic energy instead of heat passes from the outside to the inside of the crucible producing heat only where it is wanted, in the metal.

As soon as the metal starts to melt so that a pool is formed in the bottom of the crucible, violent stirring occurs in the metal

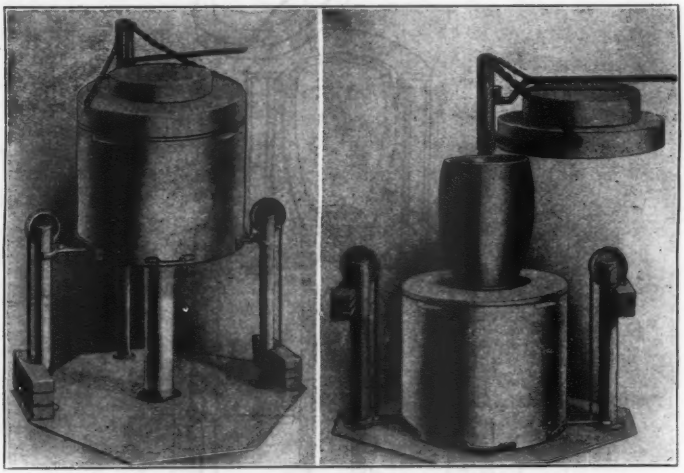

FIG. 2 FIG. 3

FIG. 2—FURNACE IN MELTING POSITION
FIG. 3—FURNACE LOWERED TO REMOVE CRUCIBLE

due to the attraction of currents set up in the outside of the bath. Fig. 4 indicates the direction of the lines of metal flow through any vertical section of the crucible. The action is such that the metal is elevated in the center about 2 inches higher than at the crucible wall. Flow lines of metal are plainly visible on the top of the metal bath going from the center radially in all directions to the edge. As the metal is forced away from the wall of the

crucible there is no wearing away due to stirring. Floating lumps of metal stay in or near the center of the crucible.

There is practically nothing to wear out about the furnace except the crucibles. The lining outside of the crucible is never in contact with molten metal except when a crucible breaks and the lining is not heated enough to cause any disintegration. There is, of course, some abrasion of the lining wall as it slides up and

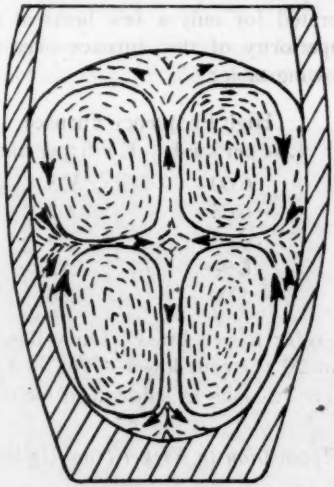

FIG. 4—LINES OF FLOW OF METAL IN CRUCIBLE WHEN IN MELTED CONDITION

down on the crucible but if the crucible is well centered, the life of the lining is very long.

The furnace housing is counterweighted and in the design shown in the illustrations the housing is supplied with a handle by means of which it can be raised and lowered without the use of power. In larger sizes provision is made for raising and lowering the housing by means of two air cylinders.

Power

The power for operating these furnaces is derived from a generator of standard design driven by an ordinary induction motor or a synchronous motor. A number of condensers are also

provided for bringing the power factor of the furnace circuit to unity. The power factor of the driving motor is usually about 90 per cent unless a synchronous motor is used in which case it can be made unity or leading.

The efficiency of the equipment is comparable with that of other electric furnaces operating on a 24 hour per day schedule. The high frequency induction furnace falls off very little in efficiency when operated for only a few heats at a time. An example of the superiority of this furnace over another make is given in the following table:

Hours	High Frequency Furnace		Other Furnace
Operation	Lbs. per kw-h.	Kw-h. per ton	Kw-h. per ton
8	6.60	303	351
9	6.63	302	338
10	6.68	299	325
24 x 5 = 120	6.95	287	...
Continuous	7.00	286	273

The figures refer to red brass. On yellow brass the kw-h. per ton are about 20 per cent lower. The first melt takes about one and a half times as long as subsequent melts.

Application to Nickel-Iron Melting

One of the recent developments in ferrous metallurgy is the manufacture of small tonnages of nickel-iron alloys practically carbon free. The high frequency induction furnace has figured largely in this development. Permalloy, which consists of about 78½ per cent electrolytic nickel and 21½ per cent electrolytic iron, was developed with the aid of one of these small furnaces in a laboratory of the Western Electric company in New York. In 1922 two 100 pound furnaces were installed at the Hawthorne plant of the Western Electric company in Chicago. It was specified that the carbon content should not exceed .06 per cent. When the writer was installing this equipment ten successive 100 pound melts of permalloy were made of which the carbon content was reported as .01 per cent, or one point of carbon in foundry parlance.

An alloy of 50 per cent electrolytic iron and 50 per cent electrolytic nickel is being manufactured at the Westinghouse Electric & Mfg. Company in a 225 pound high frequency induction furnace. The maximum carbon content is .006 per cent. The sulphur content is about the same. Otherwise stated there are only 6 parts of carbon or sulphur in 100,000.

Application to Special Alloys

The high frequency induction furnace has also proved practical for melting ferrous alloys in small quantities when the absence

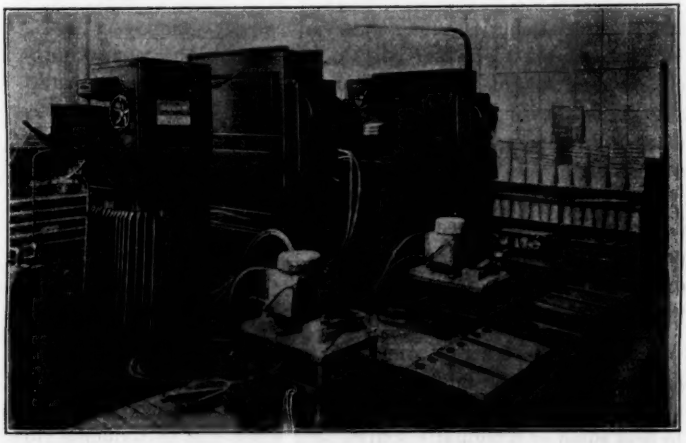

FIG. 5—INSTALLATION OF HIGH FREQUENCY CONVERTER AND TWO FURNACES

of carbon is not so important. Figure 5 shows an installation of two 15 pound high frequency furnaces which are being operated at the West Lynn plant of the General Electric Company. The metal melted is known as thermalloy and consists of 30 per cent copper, 66½ per cent nickel and 2⁹⁄₁₀ per cent iron. The balance of 1⅗ per cent consists of impurities. For such small furnaces a very high frequency current is used. Commercial power is transformed into high frequency power by means of a static appa-

ratus known as a high frequency converter. Two such converters appear in Fig. 5.

A very interesting development of high frequency furnaces has been carried on in England where the Gutta Percha Company have installed 46 units similar to those shown in Fig. 5. Sixteen pound charges of very low carbon nickel-iron alloy are melted. The crucibles in which the metal is melted are made of clay without graphite. Four of the 46 furnaces have been in use for a year or more. Sixteen were installed early in 1925 and the remaining 26 during the spring and summer of 1925.

Application to Heat Treating

In addition to melting all kinds of metals the furnace principle makes possible the heat treatment of steel and other materials. When heating magnetic metals the furnace circuit is affected when the temperature reaches the recalescense point (about 1380 degrees Fahr.) so that it is possible easily to arrange for automatic adjustment of the power supply to produce uniform heating. Thus it is possible to heat treat steel without any danger of passing the recalescense point. Strips or bars of steel can be passed continuously through high frequency furnace coils placed very close to the rolls or drop hammer in which the steel is to be worked.

For heat treating or annealing small pieces of metal a muffle or tube of heat resistant metal can be heated by means of a high frequency furnace coil around it. It is not ordinarily practicable to heat small or irregularly shaped pieces of metal by inducing current directly in them.

Summarizing the development of high frequency induction furnaces to the present time there are now on order or installed about 1500 kw. for melting non-ferrous metals, about 1200 kw. for melting ferrous metals, about 1300 kw. for miscellaneous high temperature experimental work and melting precious metals. We look forward confidently to a large expansion of the use of these furnaces for melting both ferrous and non-ferrous metals and for heat treating and annealing.

Aircraft Castings in Aluminum Alloys

By Samuel Daniels,* Dayton, Ohio

There is a well-defined trend toward the multiplication of the number of the alloys of aluminum which the foundryman may utilize. Whereas formerly he probably was acquainted with one or two types of analysis, he now hears of special compositions and of heat treatment designed to fulfill physical and mechanical requirements not attainable from his stock alloys. Most of the new alloys, and, in most cases, their heat treatment are covered by pending or issued basic patents. This situation, however, has not especially deterred their utilization, but it practically precludes the discovery of other valuable alloys except through systematic research.

The Air Service, U. S. Army, is properly very much concerned in and with the developments in the casting alloys of aluminum, both experimentally and commercially. When the war ended, there were specifications describing but two alloys; since then, four more have been added. All these alloys have one or more qualities which make them desirable for a certain class of casting used in aircraft. Sometimes the demand is solely for ease of casting; at other times it is for good mechanical properties at room temperature; and yet again it may be for strength and hardness at elevated temperature. Of equal consideration may be specific gravity, soundness, machineability, response to heat treatment, resistance to corrosion, and permanence of the initial mechanical properties. The variety of possible requisites makes it clear why so many alloys are necessary. Further experimentation should be directed not so much toward providing substitutes but more to the production of a few alloys which are self-containing in as many of the foregoing properties as is possible.

*Chief, Metals Branch, Material Section, Engineering Division, Air Service, U. S. A., McCook Field, Dayton, Ohio.

Preparation of Air Service Alloys

The Air Service regularly uses the six alloys of Table 1 in its foundry at McCook Field.

Alloys of different composition but of suitable properties, may, after granted deviation, be substituted for any of the six indicated, particularly with reference to Alloys 3 and 4. Some of the other casting alloys used by aircraft manufacturers and by the Navy are the 95 aluminum—5 silicon, the 97 aluminum—2

Table 1

ALLOYS REGULARLY USED AT McCOOK FIELD

Reference Alloy No.	Chemical Composition	Uses and Properties
1	92 Aluminum—8 Copper	For general run of foundry castings. Low strength and ductility
2	88.5 Aluminum—10 Copper 1.25 Iron—0.25 Magnesium	For parts subjected to elevated temperature
3	95.75 Aluminum—2.5 Copper 1.25 Iron—0.5 Magnesium	For parts requiring good strength and ductility as cast
4	94.0 Aluminum—5 Copper 1.0 Silicon	For highly stressed parts subjected to shock and warranting the heat treatment necessary
5	93.0 Aluminum—4 Copper 3.0 Silicon	For complicated castings with abrupt changes in cross-section
6	92.5 Aluminum—4 Copper 2.0 Nickel—1.5 Magnesium	For parts subjected to elevated temperature

Table 2

SPECIFICATION FOR ALUMINUM INGOT

Grade	Chemical Composition			
	Aluminum	Iron—Silicon	Manganese—Copper, etc.	Copper
Special	99.5 (min.)	0.40 (max.)		0.10 (max.)
A*	99.0 (min.)	0.80 (max.)	0.25 (max.)	
B	98.0 (min.)	1.50 (max.)	0.50 (max.)	

*Neither iron nor silicon content in Grade A shall exceed 0.50 per cent.

alloy.

copper—1 manganese, and the 72 aluminum—25 zinc—3 copper

Raw Materials

In the manufacture of these alloys and of the necessary hard eners, the Air Service employs aluminum, copper, cupro-nickel iron, silicon-aluminum, and magnesium.

Aluminum Ingot: Aluminum ingot, of course, is not absolutely pure. Air Service specifications describe three grades of ingot as shown in Table 2.

For ordinary purposes the aluminum content of the ingot is taken as the difference between 100 per cent and the total of the percentages of iron, silicon and copper found by analysis.

For aircraft castings primary ingot of grades A and B may be used. Whether the purer grade A or the less pure grade B is to be selected is not only a question of cost but one of the effect of the impurities in the aluminum ingot in the alloy of which it is to form the base. Any analysis of aluminum ingot is not good enough. High copper content in grade B ingot is not ordinarily of consequence because most of the alloys to be made are intentionally copper-bearing. In certain copper-free alloys, however, copper in appreciable amounts might impair the resistance to corrosion. A high percentage of iron in the ingot would not generally vitiate an alloy which was to contain a large quantity of iron, but it might in others diminish corrosion-resistance and response to heat treatment. If the silicon content in the ingot were high, it would possibly affect the machineability adversely; or, if magnesium and copper were to be simultaneously present in the final alloy, it might destroy the strength-ductility ratio. On the other hand, silicon may help to neutralize the harmful effects of iron.

The relationship of the analysis of the aluminum ingot to the constitution of the final alloy is therefore of great importance. Grade B ingot is as a rule suitable for alloys 1, 2, 4, and 5, but it has not been used for alloys 3 and 6.

Copper: Only lake or prime electrolytic copper may be used in the manufacture of hardeners. The copper content must be not less than 99.88 per cent, silver being counted as copper.

Nickel: Nickel may be introduced into the hardener either as metallic nickel of a minimum purity of 99.50 (plus cobalt) per cent or through the agency of 50-50 cupro-nickel of highest purity.

Iron: Either simple aluminum-iron (90-10) or aluminum-copper-iron (65-25-10) hardeners serve as the source of iron. Wrought iron nails or Armco iron, both practically carbon-free, may be the base materials.

Silicon: As in the case of copper and iron, silicon is added to aluminum as a hardener rather than as the pure metal. At

McCook Field the preference is for an 87 aluminum—13 silicon hardener, made from very pure materials. It is possible to obtain such satisfactory intermediate alloys (hardeners) as 80 aluminum—20 silicon and 50 aluminum—50 silicon, commercially.

Magnesium: Magnesium is added in solid form as the metal, at least 99.85 per cent pure, to the final alloy just before the latter is to be poured.

Preparation of Hardeners

In manufacturing the 50 aluminum—50 copper, the 55 aluminum—30 copper—15 nickel, the 65 aluminum-25 copper—10 iron, and the 87 aluminum—13 silicon hardener, which are readily dissolved in aluminum to form the final alloy, the following procedure is used at McCook Field:

50 Aluminum—50 Copper: Fifty parts (by weight) of copper are melted under charcoal, skimmed, and poured slowly and with stirring into 30 parts of molten (1300 degrees Fahr.) aluminum, 20 parts of solid aluminum being added gradually to the molten bath to check the rise in temperature. The hardener is then stirred, skimmed, and pigged.

55 Aluminum—30 Copper—15 Nickel: This hardener is prepared by melting together 15 parts of copper and 30 parts of 50-50 cupro-nickel with 5 parts of aluminum, which speeds up the fusion. This mixture is then poured slowly and with stirring into 30 parts of molten aluminum. Twenty parts of solid aluminum are gradually added to keep down the temperature of the bath. The hardener is stirred, skimmed, and then pigged. It will be noted that the proportion of copper to nickel is 2:1 as in alloy 6, for which it may be conveniently used without the necessity for a second hardener.

65 Aluminum—25 Copper—10 Iron: Twenty-five parts of copper are melted under charcoal, skimmed, and poured slowly and with stirring into 45 parts of molten aluminum in which have been dissolved or nearly dissolved 10 parts of iron, 20 parts of solid aluminum being added to check the rise in temperature. The hardener is stirred, skimmed, and poured into shallow ingots.

87 Aluminum—13 Silicon: This material is alloyed by melting aluminum and by plunging beneath its surface metallic silicon. The silicon, protected from oxidation by its coating of aluminum, dissolves fairly slowly in it at a temperature of about 1500 degrees Fahr. The resulting hardener is not brittle like those already described and it should be poured in shallow ingots to prevent segregation.

Preparation of Final Alloys

In making the final alloys the requisite quantities of aluminum and of hardeners are melted together. For accurate work the constituents both in the aluminum ingot and in the hardener are calculated in the charge. If magnesium is a component, it is thrust quickly below the surface of molten aluminum-hardener mixture to prevent oxidation. The bath should then be stirred thoroughly, skimmed, and pigged.

Melting for Casting

Air Service specifications demand that castings shall be made only from the best grades of virgin metals or from virgin metals and scrap of known and approved composition. Proper control of melting and of pouring temperature, which is generally about 1300 degrees Fahr., is absolutely essential and is secured through the use of a suitable thermocouple and potentiometer or millivoltmeter. Contamination of the melt by iron, dross, or by iron scale should be avoided. It is not necessary to employ fluxes to provide clean alloy.

Foundry Records

Complete foundry records of raw materials and their production and disposition are invaluable. At the McCook Field foundry the analysis of purchased and of home-prepared ingot is incorporated on cards. Each melt is given a number and assigned a "log sheet" (Fig. 1) on which are to be indicated the metallic materials and the quantity used, the furnace, the fuel, the time consumed in melting, the maximum furnace temperature, the pouring temperature, the number and pattern mark of the castings made, the number of molds of test specimens poured, the tests to be made, a sketch of the method of gating, etc. Large or impor-

tant castings are often stamped with the melt and serial number. In fact, every precaution is taken so that any matter in connection with a casting may be traced long after it has left the foundry.

The completeness with which records are kept of course depends upon conditions. Where a foundry is running day in and out on the same class of work log notes need not be elaborate;

Eng. Div. A. S. 700-McCook Field 4-19-24-1M

Foundry Log

Alloy: Aluminum Alloy 5 Composition: 4 Cu 3 Si Specification: Tentative Date 3-12-24 Melt No. 3444

CHARGE DATA

Metal	Melt No.	Composition	% of Charge	Weight, Lb.
Al-Ingot	2666	Cu 0.17 Si 0.89 Fe 1.30	88.9	266.6
Al-Cu	3090	Cu 47.00 Si 0.17 Fe 0.72	6.1	18.2
Al-Cu	3210	Cu 49.99 Si 0.20 Fe 1.04	2.2	6.4
Al-Si	1597	Si 88.83 Fe 1.16 Cu 4.47 Ca Nil	2.8	8.4
			100.0	300.0

MELTING DATA

FURNACE	FUEL						
#5	Oil	Meter No.	Couple	Max. Furnace, °F. 1500	Pouring, °F. 1450		
		Time Started 9:45	Ready 11:30	Poured 11:50	Flux None		
FURNACE	FUEL						
		Meter No. C H	Couple CA	Max. Furnace, °F.	Pouring, °F.		
		Time Started	Ready	Poured	Flux		

CASTINGS

Part No.	J. O.	E. O.	NUMBER OF CASTINGS Wanted	Cast	ACCEPTED	Total Weight of Accepted Castings, Lbs.
781		702-14-3444	2	2	2	

TESTS REQUIRED:

COMBINED DATA SHEET	CHEMICAL ANALYSIS	PHYSICAL TESTS	MICROSCOPIC EXAMINATION
✓	Cu, Si, Fe	Meldi 122 As cast	None

REMARKS:

FIG. 1—AIR SERVICE FOUNDRY LOG SHEET

but where the character of the work is constantly changing and when experimentation is required, a good set of records acts in the nature of insurance.

Characteristics of Air Service Alloys

A description of the properties of the various Air Service alloys follows. Alloys 3 and 5 are the outcome of experimentation at McCook Field, as are the specific heat treatments which are mentioned.

Alloy 1.—92 Aluminum—8 Copper

This material, known to the trade as Lynite No. 12, is by far the aluminum alloy most commonly used in the foundry. The

chemical composition and mechanical properties specified are listed in Table 3.

For aircraft work this alloy is used for a very large number of sand-cast parts lightly stressed and not subjected to shock, as, for example, in crankcases (Fig. 2), pump housings, intake manifolds, camshaft housings, covers, brackets, etc. It gives very little trouble in casting and machines freely.

As sand-cast in standard TB1 (separately cast) test specimens, shown in Fig. 3, the 92 aluminum—8 copper alloy has ap-

Table 3

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES SPECIFICATIONS OF ALLOY 1

Chemical Composition

Element	Per Cent
*Aluminum	90.0 (min.)
Copper	7.0—8.5
Zinc	0.20 (max.)
Other impurities	1.50 (max.)*

*Includes iron, manganese, tin and silicon.

Mechanical Properties

Type of Test Specimen	Ultimate Strength, lb./sq. in.	Elongation in 2 in., %
Cast-to-size	18,000 (min.)	1.5 (min.)
Machined	14,000 (min.)	

The specific gravity must not be over 2.90.

proximate properties of 20,000—1.0—60.[1] As machined, its strength is about 16,000 lb. sq. in. Its proportional limit is about 7,000 lb. per sq. in., and its tension modulus about 9,500,000 lb. per sq. in. Its specific gravity averages 2.85.

The structure is portrayed in Fig. 4. The constituents are a $CuAl_2$ network, traversed by needles of the iron-bearing constituents, in the matrix of the aluminum-rich solid solution.

The 8-per cent copper alloy is not heat treated.

Alloy 2—88.5 Aluminum—10 Copper—1.25 Iron—0.25 Magnesium

The tentative analysis and properties of this alloy are described in Table 4.

[1]Ultimate strength, lb. sq. in., elongation in 2 in., per cent—Brinell hardness, 10 mm. ball, 500 kg. load, 30 second.

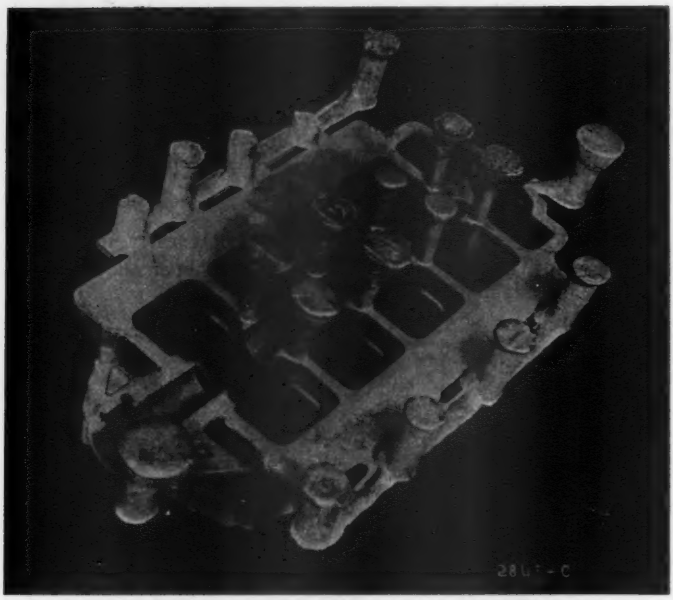

FIG. 2—LIBERTY—8 CRANKCASE IN ALLOY 1

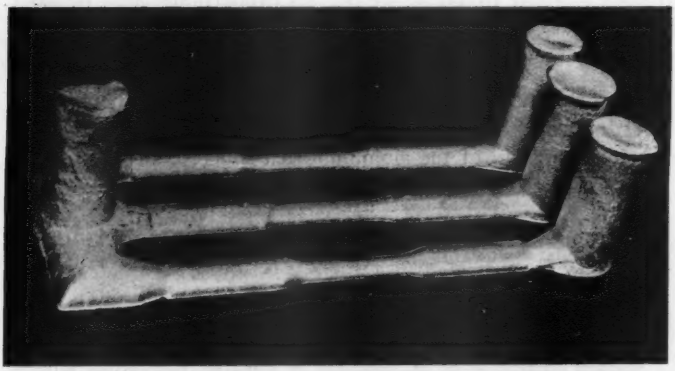

FIG. 3—AIR SERVICE TENSION TEST SPECIMEN (TB1) MOLD

In airplane engines this material, in the sand and chill-cast condition, has been used for parts needing strength and hardness at elevated temperature, such as pistons, carburetors, intake mani-

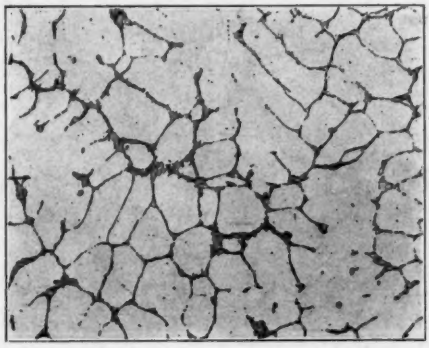

FIG. 4—ALLOY 1, AS SAND CAST—X100

folds, bearing surfaces, etc. During the war the Liberty-12 engine pistons were in this alloy, cast in permanent molds, from which it emerges much denser than when it is sand cast. The material

Table 4

TENTATIVE CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF ALLOY 2

Chemical Composition

Element	Per Cent
Aluminum	87.5 (min.)
Copper	9.25—10.75
Zinc	0.20 (max.)
Iron	1.0—1.5
Magnesium	0.15—0.35
Other Impurities	0.75 (max.)*

*Includes silicon and manganese.

Mechanical Properties

Type of Test Specimen	Ultimate Strength lb./sq. in.	Elongation in 2 in., %
Cast-to-size	22,000 (min.)	0.5 (min.)
Machined	18,000 (min.)	

The specific gravity must not be over 2.95.

machines to a better finish than alloy 1, but is more brittle and consequently undesirable for crankcases.

As sand-cast in TB1 bars, this alloy will develop 25,000—1.0—80. It is susceptible to aging at room temperature, and in

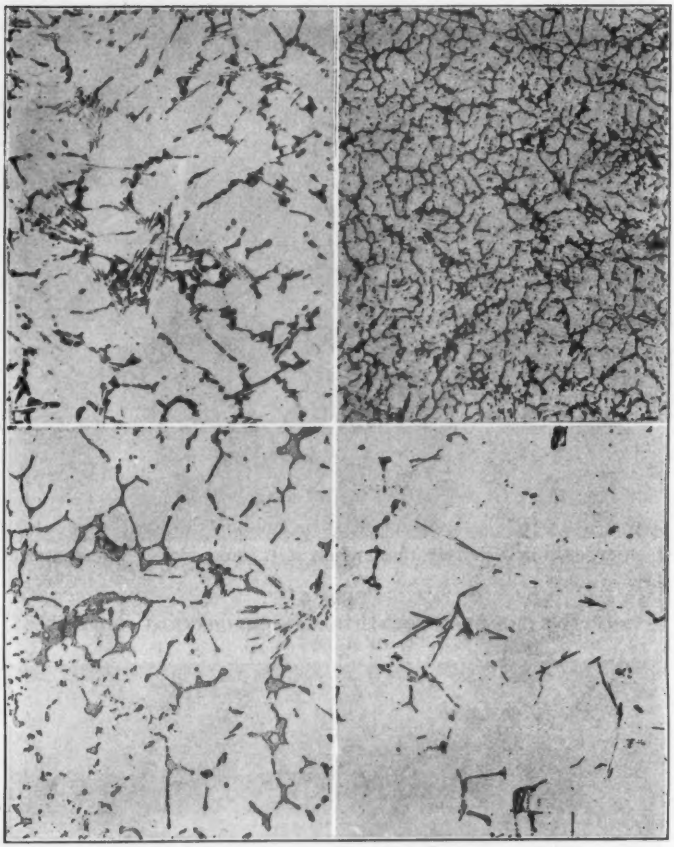

FIG. 5—(UPPER LEFT) ALLOY 2, AS SAND CAST—X100

FIG. 6—(UPPER RIGHT) ALLOY 2, AS CHILL CAST—X100

FIG. 7—(LOWER LEFT) ALLOY 3, AS SAND CAST—X100

FIG. 8—(LOWER RIGHT) ALLOY 4, AS HEAT TREATED—X100

6 months it may have attained 27,000—0.5—95. Its strength at 500 degrees Fahr. is comparable with that at room temperature.

Fig. 5 and 6 illustrate the structure of this alloy as sand and as chill-cast. The network is chiefly $CuAl_2$, crossed by iron-bearing needles, and with a lesser amount of iron-bearing skeletons. A moderate amount of Mg_2Si is present, often in filigree with $CuAl_2$.

Table 5

TENTATIVE CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF ALLOY 3

Chemical Composition

Element	Per Cent
Aluminum	94.0 (min.)
Copper	2.25—3.0
Iron	1.0—1.5
Magnesium	0.25—0.75
Other Impurities	1.0 (max.)*

*Includes silicon and manganese.

Mechanical Properties

Type of Test Specimen	Ultimate Strength lb./sq. in.	Elongation in 2 in., %
Cast-to-size	23,000 (min.)	3.5 (min.)
Machined	19,000 (min.)	

The specific gravity must not exceed 2.80.

Sand-cast pistons may be heat treated to a Brinell hardness of 120 by soaking them at 950 degrees Fahr. for 5 hours, quenching in boiling water, and aging at 400 degrees Fahr. for 2 hours. Accompanying TB1 test specimens will show 37,000—0.5—120. Chill-cast material may be heat treated to a Brinell hardness of 150.

Alloy 3—95.75 Aluminum—2.5 Copper—1.25 Iron—0.5 Magnesium

This is a material, which, as sand-cast, gives a combination of strength and ductility lying between the characteristics of the 92 aluminum—8 copper alloy and of those of alloy 4 and similar materials, supplied in the heat treated condition. Its tentative constitution and tensile and hardness properties are indicated in Table 5.

Because of its excellent mechanical attributes, this alloy finds considerable application in small parts postulating good strength

and shock resistance, where it is desired to save the expense of heat treatment. Some of its uses have been for generator adapters, yoke guides, brackets, levers, housings, and camera mounts. The alloy is not so easily handled as the 8 per cent alloy, but it machines well. The structure is that in Fig. 7.

Given a short heat treatment involving soaking at 975 degrees Fahr. for 2 hours, quenching into boiling water, and aging at 300 degrees Fahr. for 2 hours, this material in TB1 specimens will assume 31,000—3.0—68. In this condition it is often substituted for alloy 4, when the requirements permit. The alloy, as sand-cast or as heat-treated, has a fairly high degree of stability in tensile properties.

Table 6

DESIRED CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF ALLOY 4

Chemical Composition

Element	Per Cent
Aluminum	92.0 (min.)

Mechanical Properties (After Heat Treatment)

Test of Specimen	Ultimate Strength, lb./sq. in.	Elongation in 2 in., %
Cast-to-size	29,000 (min.)	4.5 (min.)

Alloy 4—94 Aluminum—5 Copper—1 Silicon.

This proprietary alloy, usually containing not much over 0.75 per cent of iron and no magnesium, is one of the more important of high strength and ductility alloys supplied in the ***heat-treated condition*** to the specification of Table 6.

The specification is very broad in that 8 per cent of constituents other than aluminum may be present provided that the manufacturer shall state his composition and the chemical limits he can maintain. The specific gravity must not exceed 2.90. The Brinell hardness lies between 65 and 80.

The 94 aluminum—5 copper—1 silicon alloy does not cast so well as alloy 1, but its vastly superior strength and resistance to shock have led to its use in crankcases, rocker-boxes, cylinder heads, and water-jackets, despite the high cost and limited sources of supply. The alloy is not particularly suitable for large, complicated castings, as it is subject to shrinks, draws, and cracks.

The heat treatment necessary to attain the tensile properties prescribed above consists substantially in heating the alloy at about 950 degrees Fahr. for from 24 to 96 hours, quenching, and aging at 300 degrees Fahr. for 2 hours. Some of its normal properties, obtained from TB1 specimens, are given in Table 7.

The structure of this material as heat-treated is shown in Fig. 8. The formation of the skeletons, which are composed of two iron-bearing constituents, is superinduced by the addition of silicon.

Table 7

TENSILE AND HARDNESS PROPERTIES OF ALLOY 4[3]

Condition	Ultimate Strength lb./sq. in.	Elongation in 2 in., %	Tension Modulus lb./sq. in.x10^6	Brinell
Sand-cast	21,000	3.5	10.5	58
Heat-treated	33,000	5.0	10.4	73

[3]See *Mechanical Properties of Al-Cu-Si Alloy as Sand-Cast and as Heat-Treated*, Daniels and Warner, A. I. M. E. Paper (Oct. 1925).

Alloy 5—93 Aluminum—4 Copper—3 Silicon

For superior casting properties, which are endowed by the addition of silicon, there are probably few alloys better than that of this composition. It does not readily crack on non-yielding cores and can be used where there are abrupt changes in cross-section or possibilities of warpage or misruns in very thin sections. It may be used in many cases in the place of alloy 1, although it is more difficult to machine. Camshaft housings, supercharger casings, intake manifolds, and a number of other parts (Fig. 9) are being cast in alloy 5.

The specifications for this material are listed in Table 8.

As sand-cast in TB1 bars alloy 5 has properties of about 21,500—2.0—55, similar to those of alloy 1, whose proportional limit, however, is higher by some 2,000 lb. per sq. in.

Its metallographic structure is that in Fig. 10. The aluminum-rich matrix contains more or less filigreed $CuAl_2$, the Al-Si eutectic, a moderate amount of needles of the (X ?) constitu-

ent, and cubes of a blue-gray constituent, probably SiO_2. Very often $CuAl_2$ is intimately associated with particles of silicon, which suggests a ternary eutectic with aluminum.

Alloy 6—92.5 Aluminum—4 Copper—2 Nickel—1.5 Magnesium

This alloy, employed as a substitute for alloy 2, is attaining increasing importance as a light material to be used at elevated

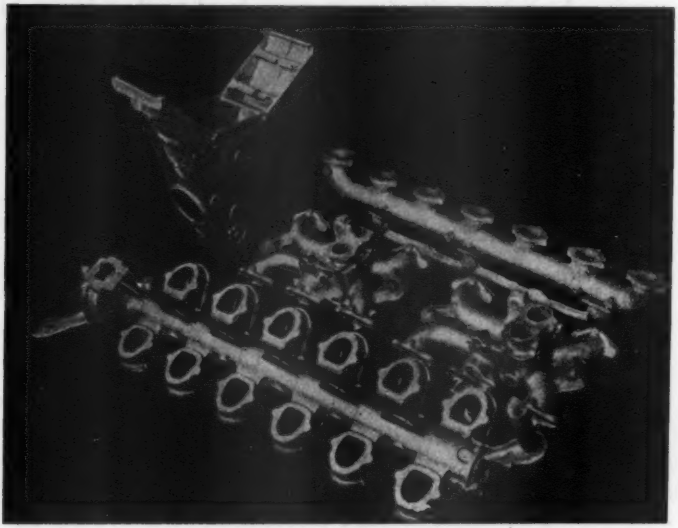

FIG. 9—SAND-CASTINGS IN ALLOY 5

temperature, such as for aircraft engine pistons, cylinder heads, and bearings. Pistons cast in green sand, with dry-sand core and chilled crown, have been quite satisfactory; and permanent molds have also been utilized. Air-cooled cylinder heads (Fig. 11) are cast in dry-sand molds. Bearings are chill cast. The machineability of the castings, which are all *heat treated*, is excellent.

The analysis and properties of this alloy must be as given in Table 9.

The foundry technique is fairly simple. The alloy should be melted under cover to prevent drossing. Castings must be gated

so that the metal does not drop long distances directly into the casting and so that it is choked as it enters the mold cavity. Chills are necessary to prevent sponginess in heavy sections. The alloy

Table 8

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF ALLOY 5

Chemical Composition

Element	Per Cent
Aluminum	92.0 (min.)
Copper	3.5 —4.5
Silicon	2.5 —3.5
Other Impurities	1.0 (max.)*

*Includes iron, tin, silicon, and magnesium.

Mechanical Properties

Type of Specimen	Ultimate Strength lb./sq. in.	Elongation in 2 in., %
Cast-to-size	18,000 (min.)	1.5 (min.)
Machined	16,000 (min.)	

The specific gravity should not exceed 2.80.

Table 9

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF ALLOY 6

Chemical Composition

Element	Per Cent
Copper	3.75—4.50
Nickel	1.75—2.25
Magnesium	1.25—1.75
Iron	0.75 (max.)
Silicon	0.50 (max.)
Other Impurities	0.25 (max.)
Aluminum	Remainder

Mechanical Properties (After Heat Treatment)

Type of Specimen:	Ultimate Strength lb./sq. in.	Brinell
Cast-to-size	32,000 (min.)	90 (min.)
Machined	29,000 (min.)	90 (min.)

The specific gravity must not exceed 2.90.

can be made extremely sound, even in sand castings. In fact, air-cooled cylinder heads must withstand a water pressure of 600 lb. per sq. in.

Alloy 6 as sand-cast in TB1 specimens gives results of 26,000—0.5—80, but after 6 months of aging at room temperature these become 28,000—0.5—95. Its strength at 500 degrees Fahr.

is about 23,000 lb. per sq. in. Tests at 600 degrees Fahr. have indicated even greater strength and that the heat-treated material is stronger than that not heat-treated.

The heat treatment comprises soaking at 950 degrees Fahr. for 4 hours, quenching in boiling water, and aging at 400 degrees Fahr. for 1 hour, which schedule produces 36,000—0.5—95 in sand-cast TBI specimens. In treating cylinder heads it is cus-

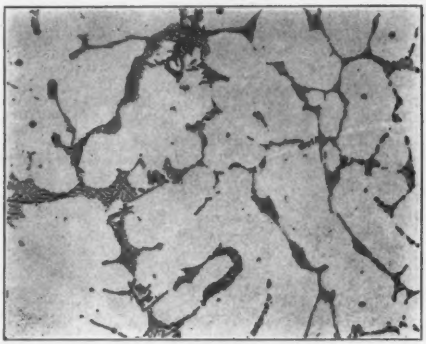

FIG. 10—ALLOY 5, AS SAND CAST—X100

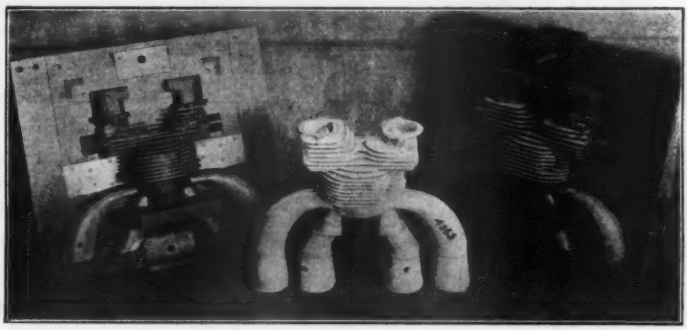

FIG. 11—AIR COOLED LIBERTY CYLINDER HEAD WITH STRIPPER PLATE PATTERN

tomary to air-quench from 950 degrees, and then to age at 400 degrees Fahr. This lowers the strength to about 33,000 lb. per sq. in., but does not sacrifice hardness. The slower cooling is necessary in order to avoid the danger of warping the fins. Heat-treated castings should have a minimum Brinell hardness of 90.

Fig. 12 is of the structure of the sand-cast alloy. The constituents are a small amount of $CuAl_2$, a fairly large quantity of $NiAl_3$ and of T (the ternary compound of copper, nickel, and aluminum), some of the iron-bearing constituents, and a moderate precipitate of Mg_2 Si. After the heat treatment described above the T constituent dissolves all of the $CuAl_2$ and some of the

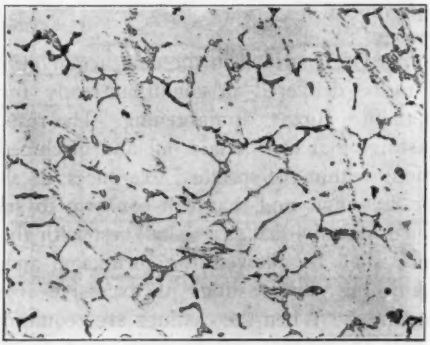

FIG. 12—ALLOY 6, AS SAND CAST—X100

$NiAl_3$. This solution progresses to marked degree with extended periods of soaking at 950° F. and it is possible sometimes to attain as high as 50,000—0.5—110 in heat treated TB1 specimens.[3]

Tests and Methods of Inspection

In order to insure that castings are in accordance with its requirements, the Air Service cites certain requirements as to matrial, workmanship, and tests. The following data are excerpts. Complete information will be furnished upon request.

[3]See "Notes on a Sand-Cast Al-Cu-Ni-Mg Alloy," Lyon & Daniels, Journ. S. A. E., 14,173 (1924).

The Casting: The alloys must be made from the best grades of virgin metals or from virgin metals and scrap of known and approved composition; and the castings therefrom shall be made by a process approved by the purchaser. These castings must be of uniform quality and condition—free from blowholes, porosity, hard spots, draws, shrinks, cracks, or other injurious defects—and shall be smooth and well-cleaned before inspection by sand-blasting, tumbling, chipping, or by other approved process. All castings must be commercially machineable and neither repaired, plugged, nor welded without permission from the inspector and then only when the defects are small and do not affect the strength, use, or machineability of the castings. No welding will be permitted on castings to be heat treated or already heat treated. Soldering is prohibited.

Unless otherwise specified in the contract or purchase order, castings are to be delivered in condition ready for machining and shall not require further straightening. The responsibility of furnishing castings that can be laid out and machined to the finished dimensions within the specified tolerances, as shown on the blue-prints or drawings, and that will conform to such gages as may be specified in individual cases shall rest with the contractor. Sufficient stock shall be allowed for shrinkage, and, where required, for finishing; but castings of excessive size or weight will not be accepted. When the castings are required to be heat-treated, the heat treatment shall be performed on the whole of the casting, never on a part only, and shall be applied in a manner that will produce the utmost uniformity. All castings in any one lot to be heat-treated shall be heat-treated in the same furnace charge.

Chemical Analysis: An analysis of each melt or lot of castings shall be furnished by the contractor, showing the percentages of the elements designated. Check analyses may be made by the inspector or through him by any Government laboratory or other designated representative and without cost to the contractor. The samples for check analyses shall be taken from tensile test specimens or from a representative casting selected by the inspector from each melt or lot. The drillings shall be taken from sound

metal below the surface; and the sample shall weigh not less than two ounces.

Tension Specimens and Tests: Test specimens may be one of two types—cast-to-size, as in Fig. 13, or machined, as in Fig. 14. When no specific form is designated, the contractor may use either type of coupon. The chilling of test coupons or

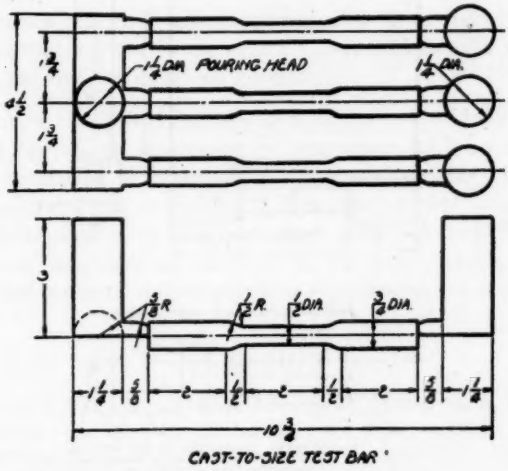

FIG. 13—DRAWING OF CAST-TO-SIZE TENSION TEST SPECIMEN (TB1) MOLD

bars shall cause the rejection of the material represented, except when the inspector has authorized the casting and test bar to be made with chills.

Each casting weighing 100 pounds or more shall have at least one test coupon attached thereto. Additional coupons may be attached at the option of the manufacturer or purchaser. In the case of castings weighing less than 100 pounds each, at least one test coupon shall be attached to one or more castings from each melt or heat or from such groups of melts or heats as the purchaser may specify, but in no case shall a lot consist of more than 500 pounds of castings. These coupons are not to be re-

moved from castings except in the presence of the inspector or until he has stamped them for future identification.

In the case of castings where it is impracticable to attach a test coupon the casting, TB1 bars (Fig. 3) shall be cast *separately* in sand, at least one test bar being poured from each melt or heat

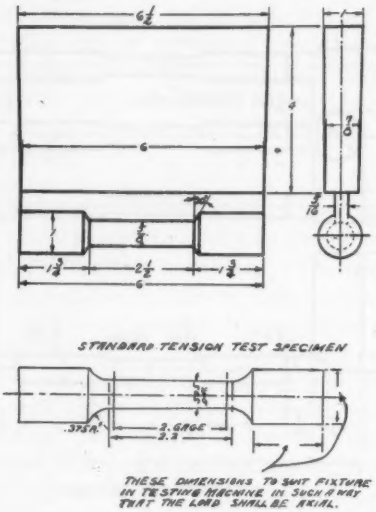
STANDARD TENSION TEST SPECIMEN
2" GAGE
THESE DIMENSIONS TO SUIT FIXTURE IN TESTING MACHINE IN SUCH A WAY THAT THE LOAD SHALL BE AXIAL.

FIG. 14—DRAWING OF MACHINED-TO-SIZE TENSION TEST SPECIMEN

of metal or from such groups of melts or heats as the purchaser may specify, but in no case shall a lot consist of more than 500 pounds of castings. The bars shall be cast from the first metal poured from the heat, and the inspector shall witness the pouring of the test mold, which he will mark for future identification. The inspector may require as many test molds as he deems necessary to establish the properties of the metal.

When castings are required to be heat treated, the coupons attached thereto shall not be removed from the castings until they have received their final heat treatment. Separately cast test bars must be cast and heat treated with the lot of castings which

they represent. Test bars may be allowed to age at room temperature for one week before testing.

If test specimens show defective machining, casting defects, unsatisfactory tensile properties, etc., an additional replacement specimen may be selected by the inspector to represent the particular lot of material. If additional test coupons are not available, the replacement specimen may be taken from the body of a casting selected by the inspector to represent the lot.

Rejection: Castings not complying with all the requirements of the specification and of the contract or purchase order shall be rejected and the contractor so notified.

Castings in which injurious defects are revealed by manufacturing operations subsequent to acceptance shall be rejected and the contractor so notified. Such rejected castings shall be held for a period not exceeding 30 days after date of notification to permit inspection by the contractor, after which period the rejected castings shall be returned to the manufacturer at his expense and replaced without additional expense to the purchaser.

DISCUSSION

MR. ALEX: I would like to ask Mr. Daniels what is meant in Table 8, Specifications for Alloy No. 5, that there are other impurities and the note states that includes iron, tin, silicon and magnesium. Does that 1½ per cent include the first 3 per cent that is added?

S. DANIELS: That is extra. It takes care of the iron, manganese and zinc. We don't like zinc in our alloys.

MR. ALEX: The note says silicon too.

S. DANIELS: That is a mistake.

I. E. WAECHTER: I would like to ask Mr. Daniels if he has found any difference in the corrosion of those different alloys he enumerated here, particularly his alloy No. 4 and alloys No. 5 and No. 6, as compared with that of alloy No. 1, where you have considerable excess of copper.

S. DANIELS: One of those questions may be answered very easily. As soon as you put three per cent of silicon in the alloy, you know you are going to increase your resistance to corrosion. Silicon cuts down

corrosion immediately of itself. Alloy No. 6 is quite resistant to corrosion. Alloy No. 4 is also pretty resistant on account of the 1 per cent of silicon it contains. Eight per cent copper alloy is more apt to corrode than any of the others.

J. B. CHAFFE, JR.: Have you performed fatigue tests on any of these alloys?

S. DANIELS: We have some data on the rolled material, not very much at the present time on the cast.

R. R. KENNEDY: I wonder if you have any information on the permanence of dimensions of these alloys. Are they subject to swelling? Are the dimensions likely to change?

S. DANIELS: On 8 per cent copper alloy, I can't say very much. On alloys No. 2 and No. 6, the heat treatment is such that it grows the alloys permanently. I would consider that five copper, one silicon would give the most trouble from the standpoint of distortion.

I. E. WAECHTER: There is one other question I should like to ask in connection with alloy No. 1: Mr. Daniels spoke about the soundness of castings usually resulting from this composition. I was wondering if it is entirely due to presence of 3 per cent silicon.

S. DANIELS: Silicon increases the soundness. If you cast a series of silicon alloys and start with a half per cent of silicon, you have very little shrinkage. Alloys rich in silicon, sometimes actually expand. Besides these alloys on this list, we cast ten or fifteen others. We cast sometimes 5 per cent silicon and sometimes 1½ copper, 12 zinc, and sometimes 3 copper and 10 zinc. There are a large number of miscellaneous alloys that we cast according to requirements.

Some Notes on the Founding of Light Alloys

By R. DE FLEURY*, Paris, France

Translation from the French by Dr. Robert J. Anderson.†

The peculiarities encountered in the founding of light aluminum alloys are due to the properties of aluminum, and these peculiarities may be markedly affected by impurities, by improper methods of founding, and by the alloying element used. The purpose of this paper is to discuss these factors in some detail since they are important as regards the kind of foundry equipment to be used and the applications of the resultant castings.

Raw Materials in Aluminum-Alloy Founding

Primary Aluminum: At the present time, aluminum producers ordinarily market two grades of metal, viz., (1) 99 percent aluminum, which contains less than 1 percent of iron plus silicon, and (2) 98-99 percent metal, which generally contains less than 1.5 percent of these two impurities, of which the iron is less than 0.8 percent. The impurities contained in primary metal are due to the method of manufacture and the raw materials employed. Generally, silicon, iron, and sodium are present. The two latter impurities are harmful, the iron mainly because of the coarse crystallization which it causes in heavy sections of castings. The presence of sodium tends to increase the corrodibility. As to silicon, this was formerly regarded as a harmful impurity, but generally quite incorrectly so, and at the present time aluminum-silicon alloys are used considerably for castings.

Another impurity, although rather rare, consists of occluded particles of the electrolytic bath. The density of the bath may, at times, with certain concentrations of alumina and cryolite, be nearly the same as that of aluminum, and particles of the bath material may be held in suspension in the metal.

*Ingénieur des Arts et Manufactures, Paris, France.
†Consulting Metallurgical Engineer, Cleveland, Ohio, and Pittsburgh, Penna.

Certain impurities may be taken up in foundry melting, notably iron and furnace gases. Combustion gases dissolve in aluminum, and rather readily at high temperatures, and on escaping during freezing in the mold tend to cause blowholes. The effects of dissolved gases are so important that they will be dealt with more fully in later paragraphs.

Aluminum Scraps: In aluminum-alloy founding, as in cast-iron work, primary (new) metal is not used exclusively, but considerable proportions of scrap are employed in the melting charges. This is simply an economic proposition, with the object of lowering costs. The following aluminum scraps are generally available on the market: viz.,

1. Aluminum sheet clippings; the amount of this scrap is considerable, and it is ordinarily of good quality since first-grade primary metal is normally used for rolling.

2. Scrap aluminum-alloy castings; this scrap consists of various parts made of different alloys.

3. Duralumin scrap, consisting of sheet clippings or ends of tubes; the composition is roughly 95 percent aluminum, 4 percent copper, plus small percentages of manganese and magnesium. The two latter elements are regarded as harmful in aluminum-alloy founding.

4. Aluminum-alloy borings; these are frequently contaminated with chips of iron or brass. In using borings, treatment should be given by magnetic separator to remove iron chips. When aluminum-alloy borings contain considerable percentages of brass or bronze chips, the amount added to a charge should be small, or else sufficient new aluminum pig should be used, also, so that the nominal composition aimed for will be secured. Borings may sometimes contain chips of bearing metals and hence antimony or lead. The effect of antimony is harmful, being similar to that of iron. The presence of excess iron or antimony in boring ingots is readily noted.

Alloying Metals: Fixed additions of alloying elements to aluminum are made with copper, silicon, zinc, brass (for copper and zinc together), and other metals depending on the alloy used.

It is advisable to ensure that the composition of the alloying metals is known, and primary first-grade metals give the best results. Brass scrap should be used with knowledge of the composition, and certain classes of brass should be excluded. Ordinary 60:40 brass scrap is recommended. Aluminum-bronze scrap may be used for introducing copper, but it should be free from iron. Silicon is used mainly in the class of alloys known as "alpax," which will be discussed in later paragraphs. In France, the silicon-containing alloys are furnished to founders by producers.

Fluxes: Certain fluxes may be used in melting practice to dissolve suspended alumina and clear the melt. These include alkali fluo-silicates, various alkali chlorides and fluorides, zinc chloride, and others. Various fluxes are on the market, especially for foundry melting and also for aluminum welding, and sold under particular trade names.

Effects of Impurities

Iron: Iron occurs normally as an impurity in primary aluminum and may be traced to a number of causes, viz., to iron in the alumina used in the reduction cell, iron contained in the carbon electrodes, dissolution of iron electrode hangers, dissolution of iron tools used in working the cell, and to pieces of iron which may accidentally fall into the bath. On remelting aluminum, iron may be taken up from iron pieces introduced with the furnace charge, e.g., in scrap, or by the reduction of iron oxide from the crucibles. With more than 1.5 percent iron in alloys, this impurity is harmful from the point of view of ease in pouring and running castings and their general surface appearance. Below 2 percent it does not harm the mechanical properties of castings. The effect of iron may be summed up as follows:

As shown by the diagram of thermal equilibrum, the introduction of a small amount of iron into aluminum causes the formation of $FeAl_3$, the melting point of which is very high. On freezing, the iron-bearing constituent solidifies first and produces a coarsely crystalline network; in heavy sections of castings this gives rise to great sponginess and porosity. It should

be added that the harmful effect of iron in an alloy is accentuated by the presence of other metals of the same group, e.g., nickel or manganese. The harmful effect of iron, as affecting the production of castings, may be difficult to trace in practice, and care should be taken that nails or other sources of iron be kept out of the melting charges. Cast-iron pots should not be used for melting, although these may appear to be little attacked.

In order to indicate what a high percentage of iron may be introduced in spite of every precaution, the following incident may be cited: A founder having noticed that certain secondary smelters were running scrap into ingots by melting in iron pots without appreciably increasing the iron content, decided to replace his graphite crucibles with iron pots in order to cut down melting costs. Excellent results were obtained in his castings production for two or three months, but at the end of six or eight months the entire output suddenly became defective and at the end of the year the entire stock of metal on hand had to be scrapped. The iron content of the metal gradually had become higher and higher.

On running scrap into ingots in the secondary plant, the metal was melted only once in the iron pots and was held for only a short time in the liquid state before being cast. In the case of the foundry, there is always a return of gates to the melting pots, and with these being melted over and over again, the iron content slowly increases. The percentage of iron is greatly increased when the liquid melt is held for a considerable time waiting for molds.

The presence of high iron in ingots is generally shown by the surface appearance, which, instead of being smooth and even, is rough and crystalline on the upper surface which solidifies freely.

Dissolved Gases: The effect of dissolved gases is a function of the temperature of heating, as may be shown by the following experiment: A cavity 2 inches deep and 1.5 inches in diameter was made in a cast-iron block. Liquid metal, heated for a given number of hours at a specific temperature in the presence of a specific gas at atmospheric pressure, was poured in.

On solidifying, the metal swelled more or less, forming a mushroom-shaped head. A section of this head showed numerous blowholes, the volume of which could be calculated with reference to the size of section examined.

On making a series of experiments like this one, using temperatures below 900 degrees Cent. and different gases, it is found that the various gases stand as follows in the order of their

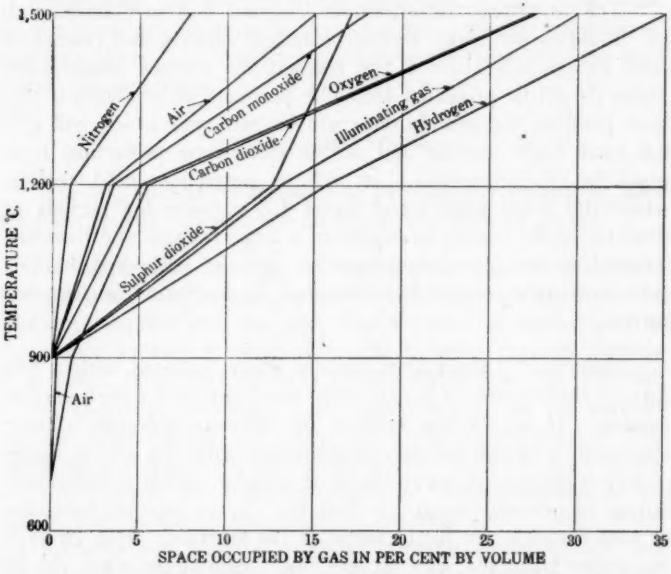

FIG. 1—VOLUME OF DIFFERENT GASES DISSOLVED BY ALUMINUM AT DIFFERENT TEMPERATURES (CZOCHRALSKI).

effects as regards blowholes: (least harmful) nitrogen, oxygen, carbon monoxide, hydrogen, and carbon dioxide (most harmful), as has been shown by Czochralski*. Fig 1 shows graphically the volumes of different gases dissolved by aluminum at different temperatures. The effect of the gases on blowholes increases

*J. Czochralski, Die Löslichkeit von Gasen im Aluminum, Zeit. für Metallkunde, Vol. 14, 1922, pp. 277-285.

markedly with increasing temperature. Above 1,000 degrees Cent. hydrogen is the most harmful, and when aluminum is heated in an hydrogen atmosphere at 1,500 degrees Cent. the volume of blowholes may amount to 50 percent of the volume of a cast section. Blowholes are due to the sudden evolution of dissolved gas at the moment of freezing, and the number and size of the holes are greater with increasing time and temperature of heating.

The foregoing considerations indicate that in aluminum-alloy founding the metal should be melted quickly and poured as soon as possible after it has reached the correct temperature. Melts should be protected from the products of combustion. In sand practice, the best furnace will be that type which will give the most rapid melting and at the same time protection from products of combustion. In die or permanent-mold casting, where the metal must stand liquid for considerable periods of time, the metal should be melted in a large furnace and then distributed to the die-casting-machine pots or individual holding pots with only enough heat supplied to maintain the temperature.

Alumina: Liquid aluminum is always covered with a thin skin of alumina which is extremely tough and has a high surface tension. If an electric current of sufficient strength to melt aluminum is passed through an aluminum wire, the wire is immediately covered with an envelope of alumina which is sufficiently strong to prevent rupture so that the electric current continues to pass through the liquid metal in the interior. This effect is maximum when the wire is very fine. Aluminum wires can be used as fuses unless the sections are very large.

The density of alumina formed on a bath of liquid aluminum is about the same as that of the metal, and above 800 degrees Cent., the alumina floats, while below this temperature it would sink if the fluidity were sufficient. Practically, these differences in density are so slight that separation cannot readily be made. When metal is remelted several times, particularly in the case of alloys run from borings, increasing amounts of alumina are taken up, which renders the melt more viscous and pasty. Even

when the degree of viscosity is apparently not excessive, the entrained alumina forms a network in the metal and encloses gas and air bubbles. This condition causes blowholes, i.e., the entrapping of gas which does not fully escape on casting. The harmful effects of oxidation on melting, with the production of alumina, can be overcome by treatment of the melt with fluxes like the alkali fluorides or still better with fluo-silicates, i.e., substances which will dissolve alumina. Zinc chloride is also used for fluxing melts. In any case, oxidation can be partly avoided by maintaining the melting temperature low. Open-flame melting furnaces are inadvisable since the hot products of combustion come directly in contact with the metal; these furnaces tend to give viscous melts.

Furnaces for Melting

Turning now to the question of furnaces for melting in casting practice, the following recommendations may be given:

If large scrap castings or ingots are to be melted, open-flame furnaces are suitable, provided that the operation can be conducted rapidly and the alloy cast as soon as melted and at the proper pouring temperature. The Charlier type of furnace is suitable. Crucible furnaces of the Rousseau type are still better, as are pot furnaces with forced draft. In the case of melting down borings or other fine scraps, natural-draft furnaces using crucibles, with the surface of the bath open to the air, are suitable for ordinary ingoting. The operation is, of course, carried out by treatment of the melt with a flux. Iron-pot furnaces may also be used for running down borings, but generally speaking, plumbago crucibles are preferable. A suitable type of holding furnace for permanent-mold casting is the natural-draft pot furnace using a plumbago crucible. In any melting operation, addition of a fluo-silicate flux should be made for the purpose of eliminating alumina and rendering the bath well fluid.

The consumption of fuel in coke-fired furnaces of several types is about as follows: In continuous melting in iron pots running scrap to ingots, 0.5 pound of coke per pound of metal.

In forced draft furnaces using plumbago crucibles, 1 pound of coke per pound of metal. In holding furnaces for permanent-mold casting, about 3 pounds of coke per pound of metal; the consumption of fuel will be still more when small pieces are being cast.

Aluminum Alloys for Founding

Aside from aluminum-silicon alloys (e.g., of the "alpax" type) all aluminum alloys have about the same general characteristics from the point of view of founding. The questions of ease of casting, contraction, facility of machining, hardness, appearance, etc., have led founders to prefer one alloy instead of another. The alloys commonly used in France, and which have been accepted by the Commission on Standardization of the Department of Commerce, are the following.

(1) 88 : 12 aluminum-copper; this is used where hardness is required, e.g., at high temperatures (pistons).

(2) 87 : 3 : 10 aluminum-copper-zinc; this is used for general casting purposes and is not suitable for applications where the temperature exceeds 100 degrees Cent.

(3) 88 : 7 : 5 aluminum-copper-zinc, made up by adding about 12 pounds of 60:40 brass to 88 pounds of aluminum.

(4) 92 : 8 aluminum-copper.

(5) 97.5 : 2.5 aluminum-copper; this is used for stamping after casting (e.g., fuses).

These alloys do not exceed 15,000-20,000 pounds per square inch tensile strength, with elongation of ½ percent, and density of 2.8-3. They have been generally used in motor-car construction and other machines. So far, the aluminum-copper alloys have been most generally used, since they are not so much affected by temperature as the others.

All of the alloys give granular fractures and are hot short. The granular effect is due to the long period of solidification (this being indicated by the distance between the liquidus and solidus on the constitutional diagram, e.g., in the aluminum-copper system). The alloys have high contraction on freezing, which will

naturally give rise to draws in heavy sections of castings and cracks where the cores are too hard. These properties of the alloys require specific methods of foundry procedure.

Owing to the long period of solidification, the alloys tend to draw in heavy sections and cause internal pipes; drawing is easily disclosed by inspection of the exterior of the massive parts,

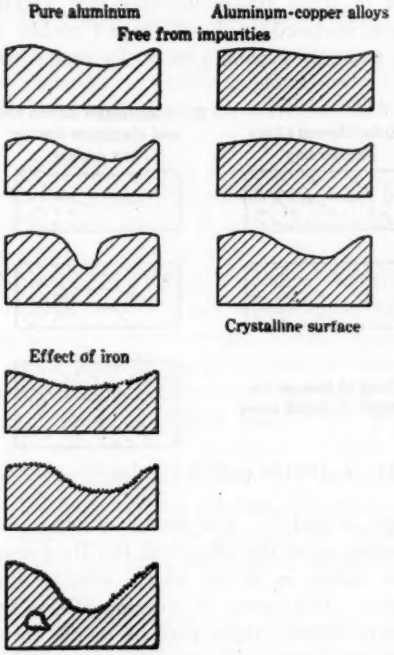

FIG. 2—PROGRESSIVE SOLIDIFICATION (LONG PASTY STATE).

which show hollowed depressions on the exterior surfaces. This does not, however, apply to "alpax," which is an eutectic alloy, nor to aluminum bronze. In these cases, the solidification is instantaneous, the parts adjoining walls solidify first owing to the chilling, and contraction produces only internal cavities. These

are, of course, not revealed by examination of the exterior surface of the casting, and the only method for determining whether the piece is sound or not is to saw it through. Before putting a casting into production, it is advisable to make thorough examination to ensure soundness.

Figs. 2 to 5, inclusive, show graphically the two types of solidification referred to, viz., progressive and instantaneous. It is assumed in these representations that given volumes of liquid alloy are enclosed in block-shaped molds with no free surface. The force of gravity acts in the case of Figs. 2 and 4,

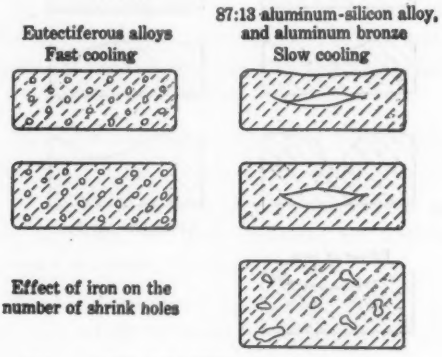
Eutectiferous alloys
Fast cooling
87:13 aluminum-silicon alloy, and aluminum bronze
Slow cooling
Effect of iron on the number of shrink holes

FIG. 3—INSTANTANEOUS SOLIDIFICATION.

but not in Figs. 3 and 5. The draws or pipes are exterior or interior depending upon the alloy and the thickness of the part. Interior draws occur in alloys which solidify instantaneously, such as eutectics. The speed of freezing affects the size of the resultant pipes or draws; these may be in the form of well defined and localized draws or in the shape of small bubble-shaped holes, which latter should not be confused with blowholes.

Table 1 gives a summary of the foundry properties of some aluminum alloys.

Aluminum-Silicon Alloys ("Alpax")

Special mention should be made of the newly patented foundry alloy which has come into use recently, viz., "alpax";

this was invented by A. Pacz of Cleveland, Ohio. In France, license for the use of this alloy is held by La Compagnie des Produits Chimiques d'Alais, Froges et Camargue and La Société d'Électro-chimie et d'Électro-métallurgie. The nominal composition of this alloy is 87 : 13 aluminum-silicon. Special treatment of this composition in the liquid state at particular temperature with alkaline-salt fluxes is necessary to give the desired properties. The special treatment is made the basis of the patents, and this need not be considered in detail here.

The following properties and characteristics of alpax may be noted from the point of view of its applications: (1) Its density is about 2.6, or 10 percent less than that of the 92 : 8 aluminum-copper alloy. (2) Its resistance to atmospheric corrosion is as good as that of substantially pure aluminum, and consequently better than that of the ordinary foundry alloy. (3) It casts well and has great soundness, making it suitable for motor-cylinder blocks, having circulating cooling water. (4) Its contraction, which is about the same as cast iron, is much less than that of the usual aluminum alloys. (5) It is not exceedingly hot short like alloys which have a long freezing range. This, together with its low contraction, makes possible the production of large and complicated castings without fear of cracks and much scrap. (6) The tensile strength exceeds 27,000 pounds per square inch, with elongation of more than 5 percent. These mechanical properties in sand-cast aluminum alloys have been hitherto unknown, and the alloy has caused a marked advance in the use of light alloys for founding. (7) The strength of "alpax" at high temperatures (e.g., 300 degrees Cent.) is far superior to that of the usual alloys.

The special properties of "alpax" have considerably extended the field of application of aluminum in general engineering construction. It may be said that "alpax" bears the same relation to the ordinary alloys that cast steel does to cast iron.

Contraction and Drawing

The high contraction of the light aluminum alloys and their tendency to pipe are the most important difficulties encountered in founding, and these factors make the founding of the light

alloys entirely different from that of cast iron. The amount of the contraction on solidification and the volume of pipe are directly proportional. The contraction in volume which results on casting is made up of (1) a sudden decrease in volume at the freezing temperature, called the solidification shrinkage, and

Table 1

CLASSIFICATION OF ALUMINUM ALLOYS ACCORDING TO FOUNDING PROPERTIES

Alloys	Low Contraction	High Contraction	Precautions	Remarks
1. Pure metals or eutectic alloys.		Pure aluminum (melting point 650° C.)		
a. With pasty state.	.....	.....	.....	.....
b. Without pasty state; instantaneous solidification.	Alpax (melting point 570° C.)	Aluminum bronze (melting point 1,050° C.)	Avoid massive sections and internal pipes.	Use chills on heavy section
2. Alloys having a lower melting point than aluminum and a wide solidification range.	Alloys containing 8-12 per cent Cu (melting range 640-544° C.)	Alloys containing 3-6 per cent Cu (melting range 650°-620° C.)	Use rather low pouring temperature.	These alloys are hot short and crack with sand rammed too hard.
3. Alloys having a higher melting point than aluminum and a wide solidification range (Impurities Fe, Mn, Sb).	Alloys containing silicon, with 2½ per cent Fe (melting range 710°-570° C.)	All alloys containing iron have high contraction because of high temperature (710°-540° C.)	Cast at high temperature, otherwise the melt will be too pasty.	Iron alloys give crystalline surfaces because of liquation. Correct by adding 2 per cent Si.
4. Alloys containing entrained alumina.	.....	.....	Treat with flux and run into ingots.	Add 2 per cent Si, when fluxing does not clean.
5. Alloys containing dissolved gas.	.....	.....	Run into ingots after melting at low temperature.	No remedy possible with alloys high in iron because high temperature is required to give fluidity; addition of 2 per cent Si may help.

(2) the contraction in the solid state from the temperature of final solidification to room temperature (measured by the coefficient of expansion). The action of the solidification shrinkage makes it necessary to feed the casting during the course of freezing so as to offset the difference in volume between the mold

and the casting until the moment of final freezing. This means that the metal ought to solidify gradually in the mold, i.e., without having some interior part in the liquid state enclosed in an already solidified mass; such a part could not, of course, be fed by risers or runners. If this condition is not secured, then piping will necessarily occur in the casting.

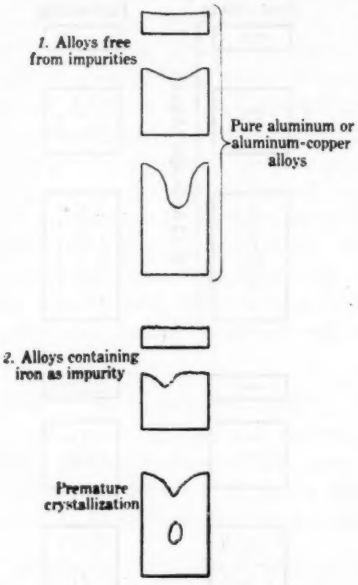

FIG. 4—PROGRESSIVE SOLIDIFICATION (LONG PASTY STATE).

The founding of cast iron is much easier than that of the aluminum alloys since the solidification shrinkage is practically *nil*. This factor is extremely important for the usual aluminum alloys and is the cause of most of the difficulties in founding. It is also important in the case of "alpax," although the solidification shrinkage of this alloy is relatively slight as compared with the other aluminum alloys. In the usual alloys, external

draws are often pronounced because of the pasty state through which they pass on freezing.

In the case of "alpax" and aluminum bronze, which are eutectic alloys and consequently solidify instantaneously, the draws are always internal and may be almost microscopic in size. It is well to consider carefully the methods for avoiding this defect in

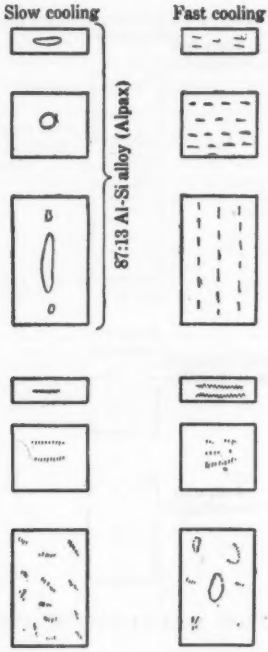

FIG. 5—INSTANTANEOUS SOLIDIFICATION.

order to obtain sound castings. Briefly, gradual cooling should be the object sought, and this may be accomplished by well-known foundry methods, e.g., chilling heavy sections. It is of interest to draw some broad generalizations concerning these methods, as regards aluminum-alloy work, which are incidentally applicable to steel founding.

As a simple example, there may be considered a casting made up of a thin section with a heavy boss, as shown in Fig. 6. Any complex casting may be conveniently considered as an assemblage of elementary parts, and in deciding on methods for gating, the separate parts can be considered individually and the difficulties of gating purposely exaggerated. In practice, it is advisable to decide arbitrarily upon the position of attachment of the feeder for a given elementary part. This position will be a pole of heat supply; light thin sections will be poles of rapid cooling; and heavy massive sections will be poles of slow cooling. These so-called poles are, of course, really zones of greater or less extent. A general rule of gating is that, on solidification up to the final freezing of individual parts of the casting, the entire casting should freeze before the gates and risers so as to ensure feeding. Referring to Fig. 6, R is the zone or pole of rapid cooling, L (the heavy boss) is a zone of slow cooling, while A (the position of the pouring gate) is the zone of heat supply. While theoretically, it may be possible to use complicated methods of gating to ensure freezing of the entire casting before the gates have solidified, in practice it is, of course, feasible to employ only economic methods.

A. For supplying heat to different portions; (1) by the choice of position of the main feeder (e.g., A of Fig. 6); (2) by supplementary feeders or runners for supplying liquid metal to certain portions; (3) by making certain parts of the mold less conductive of heat than others, e. g., using dry sand in place of green sand; and (4) by using heavy risers at particular positions.

B. For abstracting heat from different portions; (1) by using chills at exterior positions of the casting; (2) by using chills at internal positions; (3) by using supplementary cores to reduce massive sections, e.g., coring bosses; (4) by using small risers or cooling fins; (5) by slow casting, where it is possible to so fill the mold, thus effecting gradual filling so that each successive layer draws from the next following.

It is, of course, understood that in applying these methods the most feasible should be used so that the proper cooling of the casting can be secured with the greatest economy and yielding a good quality of product.

All of these above methods are not of the same technical and economic value, particularly in the case of the light alloys. The light alloys are costly and altered on successive remeltings. Moreover, the slow cooling of heavy sections causes diminution of the mechanical properties of the castings, as does pouring at high temperatures. The best procedure of casting is that which calls for the use of the least amount of metal, i.e., the smallest amount of metal in the form of risers and feeders necessary to give a good casting. The greater the amount of metal used, the more costly the production and the greater the total loss on melting. In a poorly gated casting, i.e., one where too many or too heavy feeders are used, the scrap return is excessive, and since these

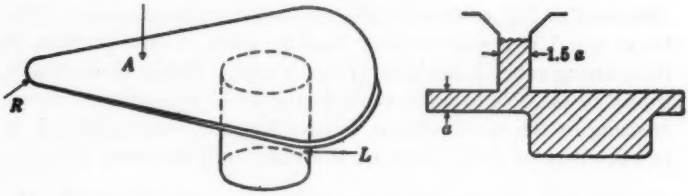

FIG. 6—EXAMPLE OF GATING A SIMPLE CASTING HAVING A THIN SECTION AND A HEAVY BOSS.

must be returned to the melting room continually the content of impurities rises higher than where the sprue return is low.

Referring to Fig. 6, the casting could be gated at the heavy boss *L*, but when so gated the zone of heat supply would coincide with the zone of slow cooling. Under this condition, the feeder would have to be very large so that it could freeze last and still feed the casting. This method is bad because a large amount of metal is required, the cooling would be slow, and the resultant grain size large.

On the other hand, the casting could be gated at the extreme end of the cold zone, i.e., at the thin section *R*. Under this condition, the chances are that the zone between the hot part and the massive boss, i.e., point *A*, would freeze first. With this gating,

it would be necessary to attach a riser to the heavy section. It is seen that such a riser ought to constitute a hot zone, but it really cannot be very hot since the metal is cooled on passing through the mold to fill it. This riser should, of course, be rather large. This method of gating presents the same disadvantages as the first one suggested.

The simplest and least expensive method of gating, and the one which incidentally avoids the necessity of using risers, consists in attaching the pouring gate at a point intermediate between the cold zone (R) and the massive boss (L), i.e., at the point A. This will provide a zone of heat supply to the main body of the casting, the feeder remaining liquid when the heavy boss has solidified. The levels of solidification will converge to the feeder and thus outside of the casting. If this gate is properly placed, it can be made rather small, e.g., diameter 1.5 times the thickness, as indicated in the sketch to the right of Fig. 6, and the casting produced without waste of metal. It is seen that this method of gating avoids the attachment of a feeder to the heavy boss, and the size of the gate is not greatly larger than the thickness of the casting at the point of feeding. As may be seen, the feeder ought to be larger than the casting at the point of attachment, and the requisite size should be obtained not by a massive section but by an elongated feeder, the thickness of which is about 1.5 times that of the casting. The position chosen makes possible feeding fairly near the heavy section, without setting up a zone of heat supply directly at the boss. This mode of gating near the heavy section permits the casting to cool gradually, does away with risers, and is generally advantageous and economical for light alloy work. Moreover, if some defects appear, the cooling of the boss can be hastened by putting on a chill at this point.

Effect of Oxidation

It has already been pointed out that a bath of liquid aluminum becomes covered with a very tenacious and elastic skin of alumina. This skin is formed immediately on all freshly exposed surfaces of metal. On casting an aluminum alloy in a mold, the frozen casting is covered entirely with a thin film of alumina. The sharpness of the mold impression imparted to the casting is due

in part to surface tension, and as the metal flows through the mold the surface skin of alumina is continually being broken and reformed. Suspended alumina in a melt decreases the fluidity, and surface oxidation should therefore be avoided as much as possible. In its flow in the mold, oxidation of metal may be reduced by avoiding too great division at the point of feeding. Oxidation, of course, takes place on pouring liquid metal into a mold.

The effects of oxidation in a mold can be decreased by suitable arrangement of skim gates, but great constrictions of section should be avoided. Skim gates, blind risers, or other suitable attachments giving change of direction to the flowing metal are advisable; the action of these is to retain the entrained alumina. Long passages for metal through the mold should be avoided, and the gating should be arranged so that the casting is fed at a sufficient number of places properly distributed. The surface skin of alumina, incidentally, renders difficult the flow of metal in the mold, particularly when the temperature is lowered by long flow passages of thin section. Proper distribution of feeders will overcome this difficulty. The surface skin of alumina hinders the flow of metal into sharp angles and corners, particularly on casting in permanent molds, and in this case it is necessary to provide vents at these places to permit the escape of entrapped air.

If an aluminum-alloy casting of fairly large surface is fed by one small gate and the metal poorly skimmed, it will be necessary to use a very high pouring temperature, and this will increase the amount of oxidation. Moreover, in order to feed it will be necessary to pour rapidly which will cause considerable breaking up of the metal and consequently an increase in the amount of surface exposed to oxidizing influences. The casting, in the vicinity of the gate, will have a dirty, drossy, and rough surface owing to the trapping of alumina. The alumina is formed in the manner already described and tends to collect at this particular point. It is often observed that in different aluminum-alloy foundries different methods of gating are used for the same kind of castings with equally good results. Actually, similar results are accomplished by proper changes of direction in the flow of liquid alloy, rather than by specific methods of gating. Long, flow passages can

readily be avoided by attaching a sufficient number of correctly distributed feeders at particular places. Under this condition, change of direction in flow can be assured so that all parts of the casting are filled up gradually. With very large castings, the pouring may be done at once from two or three crucibles, as is often necessary in iron founding.

Temperature of Casting

It has already been pointed out that the pouring temperature has an effect on the amount of dissolved gas. At the moment of freezing, dissolved gases are given off forming holes distributed throughout the casting. Holes due to gas, i.e., blowholes, are not to be confused with microscopic draws (in the case of eutectic alloys which freeze instantaneously), which have an entirely different origin. It has also been shown that pouring at a low temperature is advisable in order to ensure rapid solidification and avoid large grain size which has a deleterious effect on the mechanical properties of the casting. These considerations lead to definite conclusions, already given, as regards furnaces for melting, methods of gating, and requirements in venting.

When a variety of castings of different thickness are to be poured from the same crucible, the thinner castings should be poured first and the thicker last so that cooler metal will be put into the more massive castings, thus giving faster cooling rate. Experienced founders gage the temperature of a pot of metal by ladling out a little of the metal and pouring it on a hot brick; if the metal is very hot, the evolution of gas will be marked and little raised bubbles will appear on the surface. The melt should be cooled down until gas bubbles do not appear on making this test. Bend-test bars may also be cast; the greater the amount of bend the lower is the pouring temperature. This latter test is a good indication, also, of the composition of a given alloy, since the lower the alloying element the greater the amount of bend for a given pouring temperature. Alloys high in iron require rather high pouring temperature, and this necessarily increases the opportunity for blowhole formation.

When the iron content exceeds a certain percentage, the chances that porosity will be present are almost certain. The bad

effect of iron may be counteracted in two ways; (1) by increasing the amount of new aluminum in the melting charge, thus diluting the iron content of the alloy, and (2) by adding about 2 per cent of silicon. The presence of alumina in the melt causes increased viscosity, and hence a higher pouring temperature is needed. While castings may be made from all-scrap charges, it is usually practice to vary the proportion of scrap to new metal depending upon the nature of the castings and the difficulty in making them.

Porosity in Castings

Aside from blowholes caused by dissolved gas and porosity aggravated by high iron content, some other causes of porosity are operative. These include the premature solidification of iron or alumina. Liquation in the interior of a casting and draining of an iron-bearing network is the cause of the well known "rat's nest" structure which takes the appearance of cavities filled with needles and crystalline fissures in contradistinction to microscopic draws and blowholes which have little effect on the hydraulic properties of the casting because they are discontinuous. Porosity may be offset by (1) addition of new aluminum to the melt; (2) addition of a supplementary proportion of the additive element, e.g., copper, which has the effect of diminishing the contraction of the liquid alloy; (3) addition of silicon, which overcomes the harmful effect of high iron content. In general, the addition of silicon should not exceed 2-2.5 per cent, since otherwise the grain size will be excessively coarsened. If this amount of silicon is much exceeded, a refining process similar to that which is applied to "alpax" ought to be used, and this is, of course, covered by patents. Silicon is not added directly to aluminum, but rather in the form of an intermediate alloy to facilitate solution. This addition is advisable for aluminum alloys in general, even though they do not contain appreciable amounts of iron, since it greatly improves the casting qualities.

Permanent-Mold Casting

The light aluminum alloys are well adapted to casting in permanent molds, and the foregoing discussion as regards sand casting applies in general to permanent-mold work. The advantage

of permanent-mold casting lies in the production of castings very nearly to finished dimensions and with a considerable saving in cost over sand work if the process is correctly applied. However, all the difficulties and peculiarities encountered in sand practice are aggravated by the necessary assembly of mold and core and the steps required in removal from the mold. Moreover, permanent molds are less well adapted to changes for the regulation of thermal conditions than sand molds. These difficulties are still more aggravated by the fact that the contraction of a liquid alloy in an iron mold, and particularly around pins and metal cores, is rigidly opposed; there is no yielding as in a sand mold; and this tends to cause cracks in alloys having high contraction.

It is possible to overcome these difficulties by special care and skill in gating, each casting requiring special study to determine the proper gating. The following general rules may be given:

1. Alloys most suitable for permanent-mold casting are those having the least contraction. Of the ordinary run of alloys, those containing 10-12 per cent copper are generally preferred. Silicon-bearing alloys are very suitable for this work, since silicon markedly lowers the contraction.

2. In pouring, the entire mold ought to be at a uniform temperature in order to ensure uniform rate of cooling. The mold temperature may be kept constant by applying external heat from gas burners, or by using a definite determined rate of casting. Depending on the contour of the casting, heavy feeders may be necessary at certain positions. Under certain conditions, local heating of particular places of the mold may be necessary, and this can be readily accomplished by bunsen burners.

3. Experience shows that permanent-mold casting ought to allow the production of parts at less cost than sand casting, owing to the greater speed of the process, but rapid production may not always be possible, particularly in complicated castings or where numerous cores require setting and removal with each pour. In putting a permanent mold into production, it is first necessary to determine the proper temperature of pouring and for operating the mold and the most suitable rate of operation.

4. The relation of amount of gates and feeders to the main mass of the casting is of first-rate importance in permanent-mold work. If the casting and gates are heavy, the cooling will be slow, and this will decrease the rate of production and consequently increase costs. The rate of production for a given casting may be three times that of another depending on the casting and the method of gating.

5. Generally speaking, a new mold does not give good results until it has been in use for many hours. This is explained by the formation of small fissures in the iron which are caused by variation in temperature; these fissures allow yielding of the casting under the force of contraction and consequently diminish the tendency to cracking. These fissures do not form until the mold has been in use for some time.

6. Air vents should be provided for at sharp angles in the mold. These vents are made by drilling small holes in the mold at suitable places, and these channels should be cleaned out when they become filled with metal.

7. Molds may be cooled periodically with water during the course of casting, when it is evident that they are too hot.

Die Casting or Casting Under Pressure

Special mention should be made of the die-casting process which has been developed in recent years. Whereas in ordinary permanent-mold casting the various operations of pouring, dissembling the mold, removing the casting, and re-assembling the mold are done by hand, in die casting these operations are performed mechanically by special machines, the liquid alloy being forced into the mold shape under air pressure. Incidentally, air-pressure casting permits the production of much thinner sections than can be made in sand or permanent molds. Remarkable results have been obtained by die casting, which has been very generally employed in the United States. Aluminum alloys are well adapted to die casting, and a great variety of parts is now regularly made in the United States by this process.

The dies are made of special steel, and their construction and operation require special study and skill. There are two distinct types of die-casting machines, these having been developed from the Rohmer machine. The horizontal type is employed generally for zinc-, tin-, and lead-base alloys, while the vertical type having a closed crucible placed below the die is used for aluminum-base alloys. The vertical-type machines use compressed air for forcing the liquid alloy into the mold. A die-casting machine ought to be easily operated and so constructed that there are not more than three operations between the closing of the mold and the ejection of the finished casting. Shields ought to be placed in front of the die in order to prevent accidents from the spurting of hot metal. Pyrometric control is indispensable in the operation of die-casting machines. Heating of the die-casting pots is done usually by gas because of its ease of control.

The dies are opened and closed mechanically by compressed air or otherwise so as to permit rapid operation and ejection of the castings. A die-casting machine can produce 1,000 castings in an eight-hour day. At the present time, castings weighing from about 0.2 ounce to 14 pounds are made. During the war, motor crankcases were made by die casting, but the cost of the enormous machines necessary for producing such large parts is very high. For castings weighing more than 4-5 pounds it is necessary to cool the dies, and the best results have been obtained by compressed-air cooling or with water-jacketed dies.

A coating of crude paraffin, graphite, ochre, or other substance ought to be used on the die surface. This permits easy ejection of the casting and incidentally serves to protect the die from attack by the liquid alloy. This matter of coating is especially important in aluminum-alloy die casting; the life of uncoated dies is only half that of coated dies, and the former tend to form surface cracks much more rapidly than the latter.

In general, a battery of die-casting machines is operated from a main air compressor.

In the United States, there are a number of large die-casting plants. These concerns have specialized in the process, and their methods are kept secret. The value of the products turned out

by these plants amounts to several million dollars per annum. In recent years, various manufacturing companies which use die castings in the production of machines, e.g., the General Electric Co., have installed special die-casting departments. In France, die casting has not yet been employed to much extent. The time required in making dies as well as the cost is out of proportion to the number of castings required for production parts in France at the present time. In the United States, the enormous production of similar parts justifies the use of the process, but this is out of the question in France for the present. The fact should not be lost sight of that the die-casting process has made possible the production of large numbers of castings of precise dimensions at less cost than any other process.

Founding of Magnesium

The production of castings in magnesium and magnesium alloys presents great difficulties. The three most important difficulties encountered are the following: (1) oxidation on melting; (2) casting troubles arising from moisture in molds; and (3) the low density, which makes the question of viscosity and speed of cooling more important than in aluminum-alloy founding.

Melting: It should be pointed out that magnesium or its alloys are little altered up to the melting point on heating in air, provided that the metal has not been oxidized badly in a previous melting operation. The least alteration or oxidation has the effect of creating nuclei for further oxidation. There are three particular temperatures to take note of, viz., (1) the melting point; (2) the temperature above the melting point at which the metal is sufficiently fluid to pour into a mold; and (3) that at which ignition starts, i.e., the burning temperature.

After a certain number of remeltings, usually only about two or three, the temperature at which the metal is fluid increases, while the temperature of ignition, on the other hand, decreases, so that the range of possible pouring temperature becomes smaller and finally *nil,* so that it is impossible to cast the metal. The writer has seen cases where the ignition temperature was very near the pasty state.

The remarks made previously as regards the removal of oxide from aluminum apply with equal importance in the case of magnesium. The salts employed for fluxing magnesium are generally chlorides or fluorides, e.g., carnallite. This latter is generally best; magnesium chloride hydrolizes and yields magnesium oxychloride plus hydrochloric acid, which, in turn, attacks magnesium giving magnesium chloride. Attack and alteration of the metal occurs at points where there are included salt particles.

Casting: Difficulty obtains on casting in sand molds containing any trace of water. For small pieces, dry-sand molds are satisfactory, but with large parts difficulties arise since dry sand is a poor conductor of heat and large molds cannot be thoroughly dried throughout—water remaining in the mold body at some distance from the walls. The best method is to use molds made with an oil-sand mix, burned hard. Sand may be mixed with special bitumen products free from water and rendered more cohesive by addition of special fibrous resins of the rubber type; in certain cases, the casting may be done in siliceous green sand without a binder.

Magnesium may be cast in permanent molds, but the low density and low thermal capacity make necessary heavy gates and feeders. The remarks made previously as to the oxidation of aluminum and the use of skim gates apply equally in the case of magnesium. The number of feeders required for a given casting in magnesium will be much more than in an aluminum alloy. Although magnesium presents many difficulties, interesting results can be obtained in the production of castings of light weight, e.g., crankcases for aviation engines.

Conclusions

The founding of aluminum alloys requires patterns and methods of gating entirely different from that of cast iron. It is considerably different from the usual methods employed in bronze practice which entails long feeders with local risers. In the case of aluminum alloys, it is necessary to avoid long feeders and to use risers only when essential. Steel foundry practice in general is much like aluminum-alloy founding except that in the latter

much thinner castings can be poured because of the greater fluidity.

The various points brought up in the foregoing discussion should be given close attention in order to produce good castings at the least cost with a minimum of wasters.

Written Discussion

R. J. Anderson, Cleveland, O., and Pittsburgh, Pa.

Dr. Robert J. Anderson: This paper by M. de Fleury reflects the French point of view as regards various important details of aluminum-alloy founding and should be of interest to the American industry. There are certain views of the author which do not coincide with those of American foundrymen as will be evident.

The author suggests on p. 240 that the density of alumina is substantially the same as that of liquid aluminum, which is, of course, incorrect. In discussing the contraction of liquid alloys on p. 246, he overlooks liquid shrinkage. In general, the author insists on using a relatively small amount of gates and feeders, and it appears from the paper that in French practice the amount of sprue returns in light-alloy work is much less than that in American practice. It is well known that in American plants, in sand casting, the average sprue return is around 0.6 pound per pound of finished casting, referring to a variety of castings such as produced in a general automotive foundry. It would be interesting to learn what is the actual average sprue return in French practice.

X-Ray Examination of Aluminum-Alloy Castings for Internal Defects

By Robert J. Anderson*, Met. E., D. Sc.

Introduction

The object of this paper is to discuss briefly the application of X-ray examination to aluminum-alloy castings and to present the results of some recent experimental work. X-ray examination promises to be one of the most important testing methods in foundry practice, and it is particularly well adapted to aluminum-alloy castings because of the relatively high transparency of aluminum.

The examination of castings for internal flaws and defects by X-rays is a comparatively recent development and so far has been applied only in isolated instances as a method of test in commercial practice. Considerable progress has been made in the past five years in the technique of radiography, simultaneously with the development of the Coolidge tube. The bulk of the practical metal radiography carried out to date has been on steel castings and notably by Lester at the Watertown Arsenal. It is of especial interest to foundrymen that this work has been concerned in large part with the diagnosis of casting defects, as shown by radiographs, and the correlation of defects with methods of gating. Data as regards proper exposures for taking radiographs of different thicknesses of steel have also been made available by the work at the Watertown Arsenal. So far, the method has been but little employed in the non-ferrous field, and data as regards exposures for different thicknessss of copper, or aluminum-alloy parts are scant.

X-ray examination offers an important test method in the production and use of castings and other parts for engineering construction. The advantages of the method may be summed up

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as follows: First, inspection may be made of parts without cutting or otherwise damaging them. Second, dangerous flaws, which might cause failure of a part, can be detected before the part is put in service. Third, flaws, which might be uncovered on machining and thus cause rejection of the part, can be located before expensive machine work is done. Fourth, correlation of the nature, amount, and distribution of the internal defects in castings may be made with the method of gating or some other important factor, thus giving direct information as to the causes of flaws. Fifth, soundness can be insured, thus permitting the use of smaller sections and a lower factor of safety, with simultaneous decrease in cost. The main disadvantage of the X-ray examination is the cost; this is high where high-voltage tubes and deep-therapy apparatus are required, as for steel, owing to high cost of equipment. The cost for aluminum-alloy examinations would be relatively low when using radiator-type tubes.

The status of any casting as regards internal flaws and variable thickness of different parts can be fully determined by the X-ray examination, up to the limits of penetration. The number of radiographs required depends, of course, on the size and contour of the casting and the nature of the information needed.

Acknowledgement: The writer wishes to acknowledge with thanks facilities made available by Prof. John T. Norton in charge of the X-ray laboratory, Massachusetts Institute of Technology, Cambridge, Mass., and suggestions offered by him during the course of the experimental work.

Apparatus and Equipment for Radiography

Radiographs are shadow pictures, and the image produced on the plate or film is actual size. Briefly, a radiograph is made by exposing a photographic plate or film to the X-radiation from a Coolidge tube passed through the part to be examined. The fluoroscopic method, as employed in medical work, is not used for metals, but it may be applicable, for the detection of flaws in very transparent metals.

When a beam of X-rays falls upon a piece of metal, part of it is absorbed (being transformed into characteristic radiations of

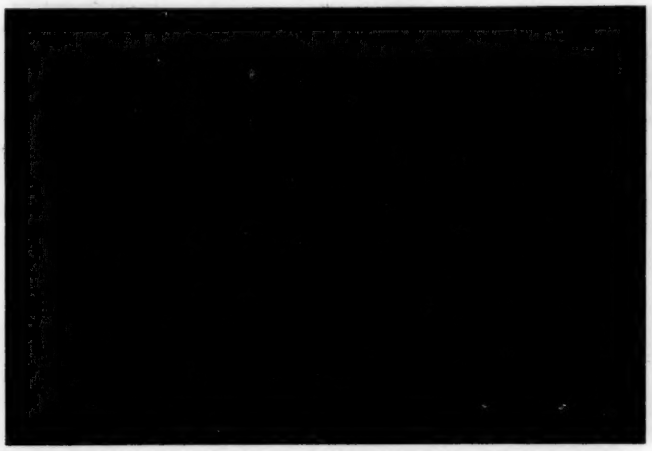

FIG. 1—RADIOGRAPH (ACTUAL SIZE) THROUGH SIDE WALL OF 12-CYLINDER AVIATION-ENGINE CRANKCASE; SHOWING GENERAL UNSOUNDNESS (55 KV., 19 MA., 12 SECS., NO SCREEN).

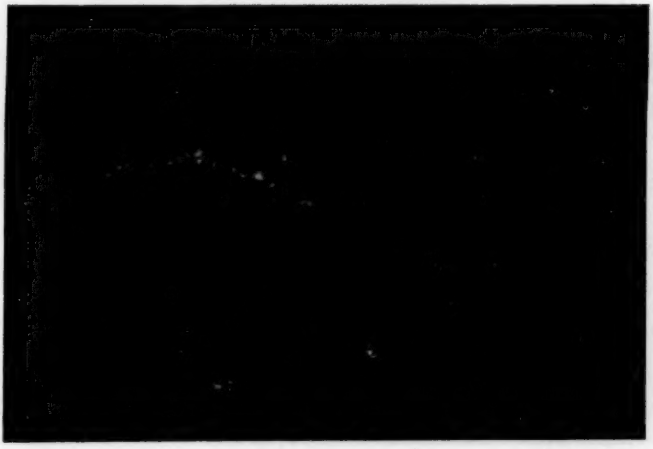

FIG. 2—RADIOGRAPH (ACTUAL SIZE) THROUGH SIDE WALL OF 12-CYLINDER AVIATION-ENGINE CRANKCASE; SHOWING BAD FLAW (55 KV., 19 MA., 12 SECS., NO SCREEN).

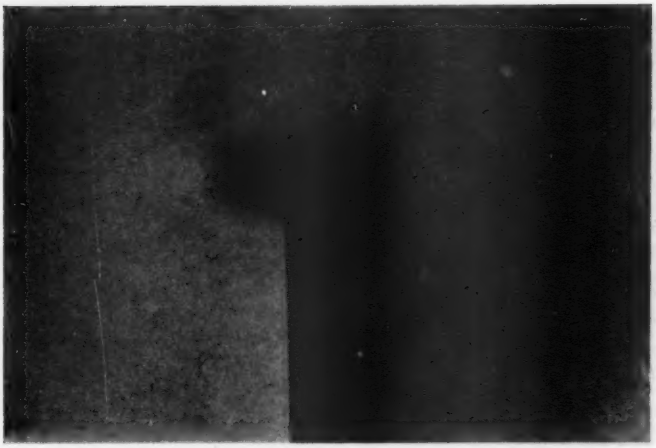

FIG. 3—RADIOGRAPH (ACTUAL SIZE) THROUGH SIDE WALL OF 8-CYLINDER MOTOR CRANKCASE; SHOWING INTERNAL BLOWHOLES AND HEAVY LUG (90 KV., 22 MA., 12 SECS., NO SCREEN).

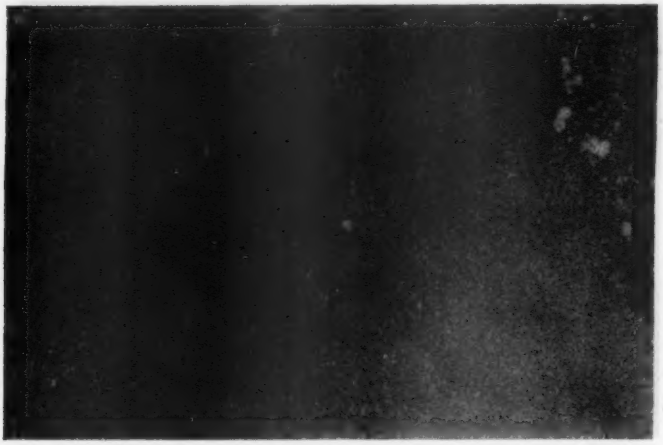

FIG. 4—RADIOGRAPH (ACTUAL SIZE) THROUGH SIDE WALL OF 8-CYLINDER MOTOR CRANKCASE; SHOWING INTERNAL FLAWS AND NUMERAL FOUR RAISED (90 KV., 22 MA., 12 SECS., NO SCREEN).

the metal), part is scattered or dispersed (the direction is altered), and part passes through. Roughly, the amount of absorption and scattering is a function of the composition of the metal, its density, and thickness, and the wave length of the radiation. Opacity to X-rays, or the transparency of a substance, is measured by the number and weight of the atoms. The atomic number of aluminum is 13, as against 26 for iron, while the density is 2.7, as compared with 7.85 for iron.

The apparatus required for radiography is well known and has been frequently described. In the present experiments, two

FIG. 5—RADIOGRAPH (ACTUAL SIZE) THROUGH BELL WALL OF 8-CYLINDER MOTOR CRANKCASE; SHOWING BLOWHOLES AND VARIATION IN THICKNESS OF SECTIONS (165 KV., 2 MA., 180 SECS., NO SCREEN).

types of equipment were used, viz., (1) a Victor-type deep-therapy machine, with high-voltage Coolidge tube capable of operation up to about 260 kv., and (2) a self-rectifying unit, with radiator-type Coolidge tube, capable of operation in the range 55-90 kv. Experiments were made as regards suitable exposures for different thicknesses of aluminum-alloy castings, varying the voltage over a considerable range. For aluminum, a self-rectify-

ing unit, such as is used for fluoroscopy and ordinary medical radiography, is suitable, but the deep-therapy type of machine with hign-voltage tube is essential for penetration of any considerable thickness of heavy metal. A radiator-type tube with auto-transformer suitable for the radiography of aluminum-alloy castings can be purchased for around $700, which makes an economical proposition.

Exposures Suitable for Aluminum Alloys

One of the main objections to X-ray surveys in the case of large steel castings is the comparatively long time required for exposures. Moreover, for thick sections of steel, very high-voltage tubes and expensive auxiliary equipment are needed. With the tubes now available, there are definite limitations to the thickness which may be penetrated with practical exposure limits. With the high-voltage tube operating at around 200 kv. and 7 ma., the time required for penetrating 3 inches of steel is about 30 minutes. According to Lester, 6.8 inches of steel could be penetrated with a 400 kv. tube in 30 minutes, if such were available.

In contrast to steel, aluminum and its light alloys are relatively transparent, and penetration of comparatively heavy sections may be made in short times. Thus, a section of 92:8 aluminum-copper alloy casting 2.5 inches thick can be penetrated to give a good radiograph with an exposure of 30 seconds, using 165 kv. and 2 ma., an intensifying screen being employed with the film. Without the screen, an exposure of about 3 minutes is required. Steel castings are thus about 10 times as opaque as aluminum-alloy castings. Long exposures in radiography are undesirable, particularly in the detection of small defects in the interior of thick masses of metal, because the scattering effect producd by the thick mass between the defect and the film will fog the definition. The sensitivity of the X-ray examination to the detection of small internal defects depends upon the thickness of the section examined, and the sensitivity is less as the thickness is greater. Increase of potential increases the penetration and for a given thickness of metal reduces the time period of exposure.

Blowholes, draws, cracks, and related defects in castings appear as dark spots or areas on the X-ray negatives or as light spots on the X-ray prints. Inclusions would appear as light spots on the negatives if the included matter were more opaque than the matrix of the casting, e.g., a bit of iron nail included in an aluminum-alloy casting.

Exposure, in radiography, is conveniently measured as the time (in minutes or seconds) multiplied by the current (milli-

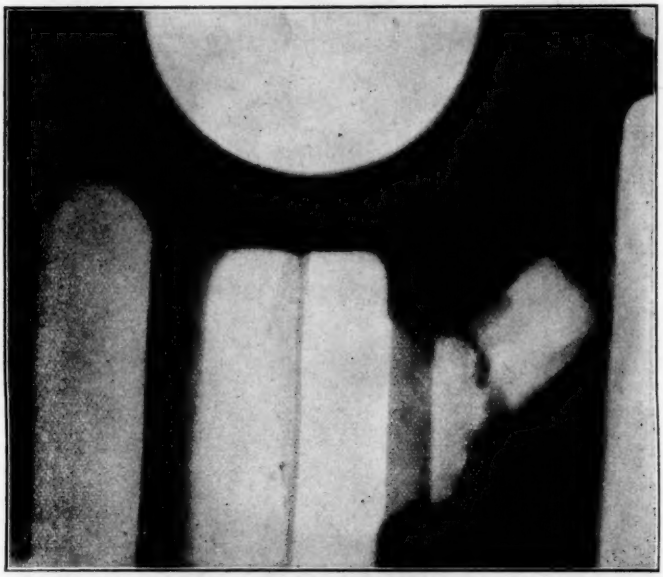

FIG. 6—RADIOGRAPH (REDUCED FROM 5 INCHES ACTUAL WIDTH) THROUGH FIRST BEARING RIB OF 8-CYLINDER MOTOR CRANKCASE; SHOWING LARGE HOLE (165 KV., 2 MA., 30 SECS., WITH SCREEN).

amperes consumed in the tube) for a given imposed voltage. Thus, an exposure of 12 seconds at 2 ma. is given as 24 ma.-secs. (with 165 kv., for example). Penetration is a function of the potential, as already indicated, and this is increased by increasing the voltage, i.e., increasing the transmitted radiation. The time required for exposure varies depending upon whether

intensifying screens are used or not; with screens, the exposure varies with the kind of screen and its age—screens deteriorate with use. In the present experiments, radiographs were taken using intensifying screens having a speed of about 10 times, and also without screens. This distance between the castings and the tube targets was made as large as possible in order to reduce distortion effects to a minimum; this distance was generally 42

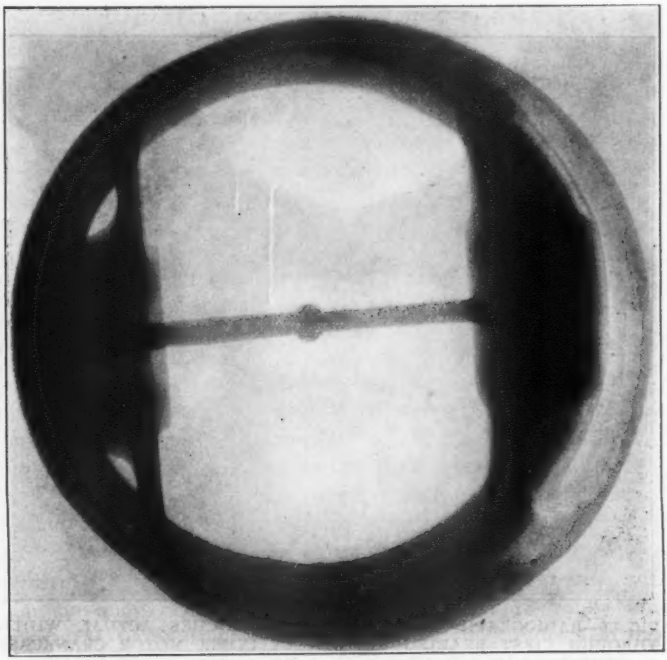

FIG. 7—RADIOGRAPH (REDUCED FROM 4.5 INCHES ACTUAL WIDTH) OF CHILL-CAST PISTON (165 KV., 2 MA., 30 SECS., WITH SCREEN).

inches in the case of the high-voltage tube and 30 inches in the case of the radiator-type tube. Eastman duplitized X-ray films were employed.

Some few data as regards suitable exposures are given below, as applying to the radiography of light aluminum-base al-

loys: Using high voltage Coolidge tube operating at 165 kv., 2 ma.; no screen, from 20 seconds for $\frac{3}{16}$-inch thickness to 180 seconds for 2.5-inch thickness; with screen, from 5-10 seconds for $\frac{3}{16}$-inch thickness to 30 seconds for 2.5-inch thickness. Using radiator-type tube operating at 90 kv., 22 ma.; no screen,

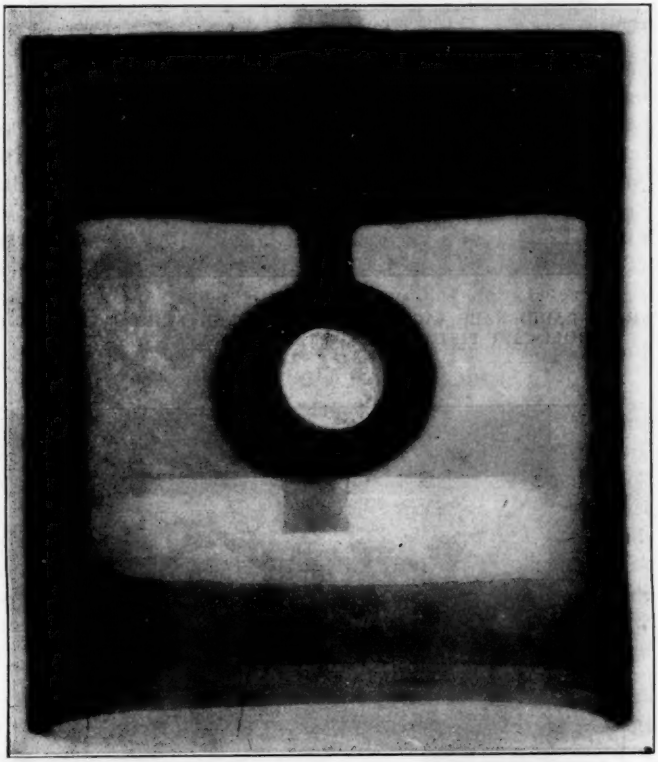

FIG. 8—RADIOGRAPH (REDUCED FROM 4.5 INCHES ACTUAL WIDTH) OF CHILL-CAST PISTON (165 KV., 2 MA., 30 SECS., WITH SCREEN).

from 10 seconds, for $\frac{3}{16}$-inch thickness to 90 seconds for 2.5-inch thickness. In the case of the radiator-type tube, when penetrating thicknesses requiring exposure of much more than 30 seconds, the radiographs may be taken by making several ex-

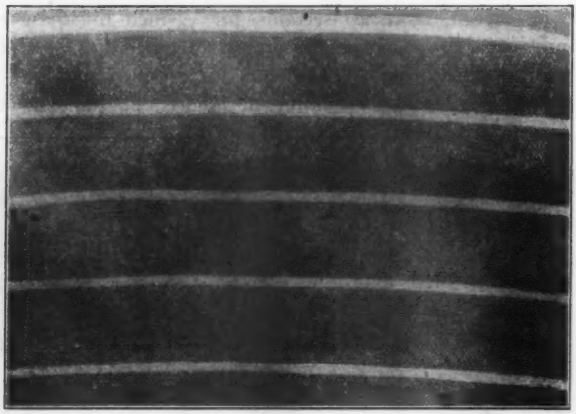

FIG. 9—RADIOGRAPH (ACTUAL SIZE) THROUGH SKIRT OF MACHINED CHILL-CAST PISTON (165 KV., 2 MA., 180 SECS., NO SCREEN).

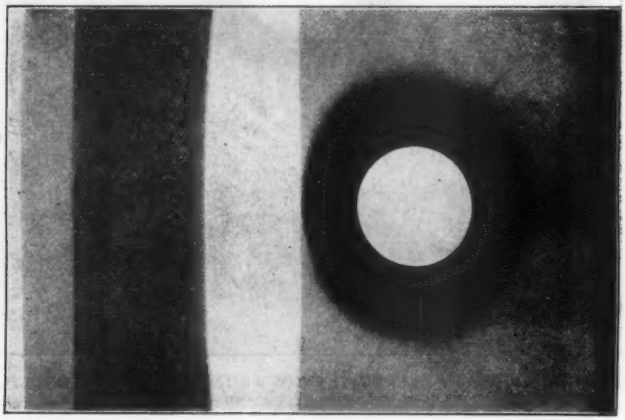

FIG. 10—RADIOGRAPH (ACTUAL SIZE) THROUGH BOSS AND SKIRT OF CHILL-CAST PISTON; SHOWING ISOLATED BLOWHOLES ON RIM (165 KV., 2 MA., 120 SECS., NO SCREEN).

posures of 25 seconds in order to avoid damaging the tube. In any case, it may be necessary to make several different exposures at a given section in order to secure an X-ray negative of the desired density to give good prints and to show well the particular flaws present.

Typical Radiographs Made On Some Aluminum-Alloy Castings

Various representative aluminum-alloy castings, including crankcases for aviation engines and motor cars, pistons, vacuum-cleaner parts, housings, runners and gates, etc., were examined during the course of the investigation. In the case of large parts like crankcases, in order to determine the status of the casting, it is advisable to survey the part by the method of taking numerous small radiographs at virtually all feasible positions. In the survey, for example, of a crankcase upper half for a 12-cylinder aviation engine, some 90 radiographs were taken, while in the instance of a crankcase for an 8-cylinder motor-car engine some 50 were taken. The accompanying radiographs of Figs. 1 to 15, inclusive, show some typical results.

Fig. 1 is a radiograph taken through the wall on one side between the fifth and sixth bearing ribs of a 12-cylinder aviation-engine crankcase. This radiograph is typical of aluminum-alloy sand castings which show general unsoundness. Sand-cast aluminum alloys are normally unsound, as contrasted with chill-cast alloys; radiographs of the latter have an entirely different appearance. Fig. 2 is a radiograph of another part of the side wall of this crankcase at a position between the third and fourth bearing ribs. The curved flaw is a lap or possibly a gas line.

Fig. 3 is a radiograph taken through a portion of a side wall of a crankcase for an 8-cylinder automobile motor. The large black area shows the position and shape of a heavy lug (¾-inch thick) attached to the outside of the wall. The white spots on the radiograph are internal blowholes. The exposure was suitable to show the defects in the thin side wall (⅜-inch thick) but not to show any which might be in the lug section (1⅛-inch thick). The radiograph indicates how differences in thickness are shown. Fig. 4 is another radiograph taken through a side

wall of this crankcase at a position between the second bearing and second reinforcing rib. Blowholes and general unsoundness are indicated. In Fig. 4 it will be noticed that a dark area has the shape of the arabic numeral four; this was a slightly raised ($\frac{1}{16}$-inch thick) numeral cast on the wall of the crankcase. Fig. 5 shows a radiograph taken through the wall of the bell of this same case; the large round hole indicated (lower right-hand)

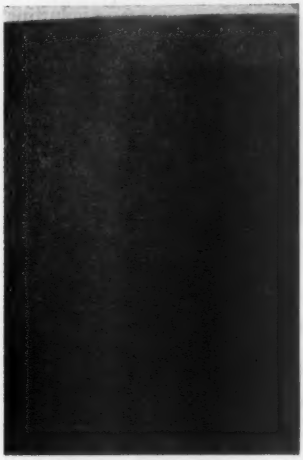

FIG. 11—RADIOGRAPH (ACTUAL SIZE) THROUGH SKIRT OF CHILL-CAST PISTON (90 KV., 22 MA., 12 SEC., NO SCREEN).

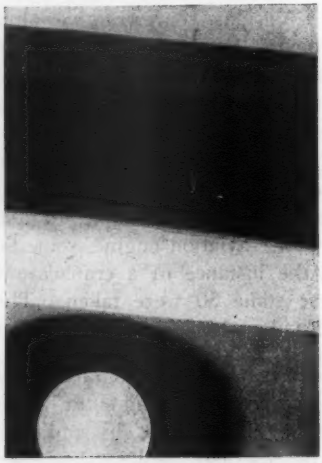

FIG. 12—RADIOGRAPH (ACTUAL SIZE) THROUGH RIM AND BOSS OF CHILL-CAST PISTON (90 KV., 22 MA., 22 SECS., NO SCREEN).

was a cored hole; blowholes are seen in the upper left-hand corner, and variable thickness of section is indicated. Fig. 6 shows a large hole in the first bearing rib of this case (the white patch in the lower part).

Fig. 7 shows a shadowgraph of a chill-cast piston, taken with the piston standing on its head on the film, while Fig. 8 shows the same piston taken lying on its side. Fig. 9 shows a radiograph taken through the skirt of a machined chill-cast piston, the radial lines being oil grooves. Fig. 10 is a radiograph taken through a boss and skirt area of a chill-cast piston; small blow-

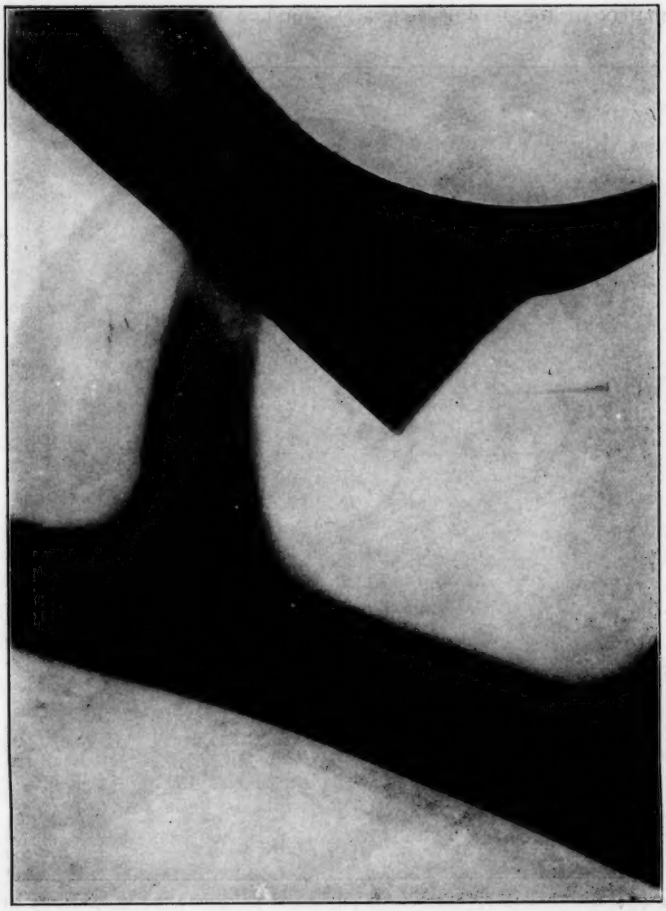

FIG. 13—RADIOGRAPH (ACTUAL SIZE) OF GATE AND RUNNER SYSTEM; SHOWING DRAW (90 KV., 22 MA., 15 SECS., WITH SCREEN).

holes are seen in the rim (left-hand upper corner) and one in the skirt (right-hand upper corner). It will be noticed that the matrix of the skirt is generally sound in the case of this chill-

FIG. 14—RADIOGRAPH (REDUCED FROM 6.75 INCHES ACTUAL WIDTH) OF A VACUUM-CLEANER CASTING (165 KV., 2 MA., 12 SECS., WITH SCREEN).

cast piston as contrasted with sand-cast products. Fig. 11 shows a radiograph through the skirt wall of a chill-cast piston, while Fig. 12 shows one taken at the rim at the end of the skirt; in

the latter, the small raised numerals which are cast on the piston to indicate the date were plainly visible on the negative, but rather dim on the reproduction.

Fig. 13 shows a radiograph of a gate and runner system used to feed a casting; a marked external draw existed at a juncture of two passages as shown by the light area.

Fig. 14 shows a silhouette of a vacuum-cleaner casting.

Fig. 15 shows a radiograph of a section of a forged duralumin connecting rod for an automobile motor, indicating absence of internal defects.

Resumé and Conclusions

Discussion is given of the field of application of X-ray examination to aluminum-alloy castings, and typical radiographs made of commercial castings are shown. It is pointed out that X-ray examination is of great advantage in detecting serious internal flaws before a part is put into service and in studying gating practice. Gating is a matter dependent upon the judgment and experience of men skilled in the production of castings. X-ray examination will go far in throwing light on the reasons for specific gating methods and the causes for wasters due to improper gating.

Radiographs can show such flaws as blowholes, inclusions, draws and shrinkage cavities, general unsoundness, cracks, sand holes, variations in thickness, and other defects commonly found in castings.

General experience and the results of tests have previously shown that permanent-mold cast aluminum alloys are more sound and have better mechanical properties than the same alloys when die or sand cast. The X-ray examination shows that the permanent-mold cast product is uniformly sound throughout as contrasted with die castings which are excessively porous and blowholey beneath the surface skin and with sand castings which generally show a more or less porous condition. Permanent-mold castings do show isolated blowholes, but these are generally small. Soundness in castings is desirable in order to avoid large sections and excess metal to compensate for porosity.

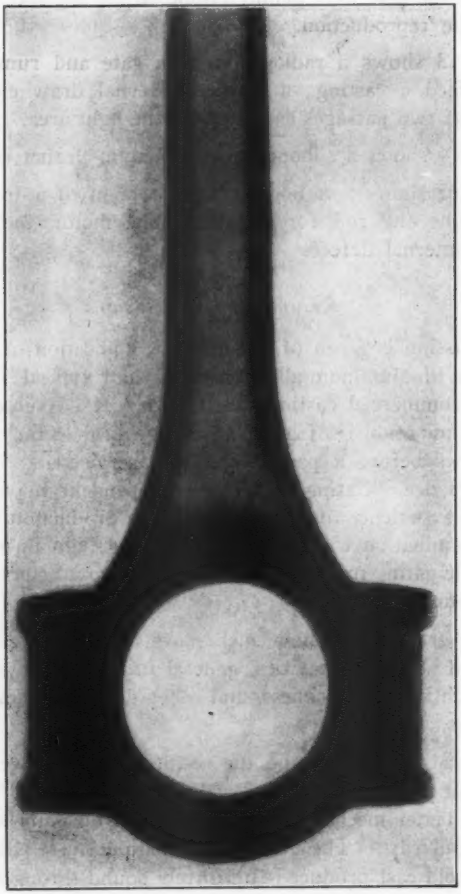

FIG. 15—RADIOGRAPH (REDUCED FROM 8 INCHES ACTUAL HEIGHT) OF END OF FORGED DURALUMIN CONNECTING ROD (165 KV., 2 MA., 15 SECS., WITH SCREEN).

Exposures for radiography of aluminum-alloy castings are short as compared with steel. Radiator-type tubes, which, together with the necessary auxiliary equipment, are comparatively inexpensive, are suitable for the radiography of aluminum-alloy castings. Thus, with the low-voltage tube operating at 90 kv., penetration of 2.5 inches can be made in about 90 secs.

As previously pointed out, the advantages of the X-ray examination include the following: First, inspection of castings can be made for internal defects without injury to parts by cutting or otherwise. Second, dangerous flaws which might cause failure of a part, can be readily detected before the part is put into service. Third, flaws, which might be uncovered on machining and thus lead to rejection after much expensive machine work has been done, can be located before machining is started. Fourth, gating methods can be correlated with resultant flaws thus giving direct information as to the effect of gating practice on defects. Fifth, soundness of castings can be ensured, thus permitting the use of smaller sections and a lower factor of safety, with simultaneous decrease in cost. Where flaws cannot be entirely avoided, they may be located, by suitable adjustment of gating methods, in parts of the casting where they will do no damage.

Producers of aluminum-alloy castings might profitably inquire into the application of X-ray examination as a practical control test in regular production.

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DISCUSSION

SAMUEL DANIELS: I would like to ask if Mr. Anderson has any idea what it would cost to make X-ray photographs on a commercial scale.

R. J. ANDERSON: I have no figures because I haven't done it commercially. If you can get any volume of work, it shouldn't be much. Of course, right now one would like to charge a lot of money for X-ray pictures because they are new and not many people make them; in fact, very few, but it shouldn't cost much. If you can get any volume you ought to be able to do it for $5.00 or $10.00. It doesn't take long. It only takes half a minute to make the exposure. Of course, if you are going to make a survey of large castings, it will run into a lot of money.

S. DANIELS: How large an area can you cover with one exposure? How much of a task is it to explore a casting?

R. J. ANDERSON: You can cover quite a large area, depending on how much you want your rays to depict. The trouble involved is in

some cases you have to take four or five pictures at one place in order to get a good photograph of a defect. If there is a defect and you don't know where it is until you have taken the picture, the film of that defect may not be what you want. You may have to take two or three in the same place, varying your exposure and developing until you get what you want. In surveying castings, it is advisable to take numerous small pictures and then one big one, that is, going over the whole area.

Permanent Mold Aluminum Castings and Their Field of Usefulness

By J. B. Chaffe, Jr.,* Cleveland, O.

Permanent mold aluminum castings are made by pouring molten aluminum alloys into warm metal molds with no external pressure applied to the metal.

The equipment used is about the same as an automobile mechanic or a small shop has available for pouring babbitt bearings —a holding furnace and pot, a ladle and a mold. It is probably on account of the simplicity of equipment and the success attained in pouring babbitt and other low shrinkage white metal alloys, that many manufacturers and foundrymen have tried to use the process and have been unsuccessful.

To the layman, and even to many versed in the engineering trades, there is an appeal in the idea of making a mold only once, filling this with the molten metal repeatedly, and getting smooth accurate castings. The writer is surprised that promoters and stock salesmen have not seized upon this appeal and let oil wells, gold mines and radio manufacture have a partial vacation.

However simple it seems, and however successful have been the experiments with other white metal alloys, there is a "nigger in the woodpile" with aluminum alloys, and that "nigger" is crystallization shrinkage.

The shrinkage in volume on freezing with the most commonly used aluminum alloys amounts to nearly 7 per cent and even with the newer low shrinkage aluminum alloys, it amounts to about 5 per cent.

To get a solid casting, this shrinkage must be fed with hot metal. The molds therefore are designed so that there is a progressive freezing from the furthest points of the casting to the gates, and the gates and sprues are the last parts to freeze.

*The Permold Co.

If this requirement is not met, there are sinks on the surfaces which are the last to set when the mold is hot, or there is porosity if the mold is somewhat cold. Almost always the fault appears on the surface and is so evident even a casual inspection would reject the casting.

Aluminum alloys also have a high coefficient of thermal expansion, and a marked weakness at very high temperatures. These factors suggest the need of ejection of the casting from the mold at the right time, and only experience can determine this.

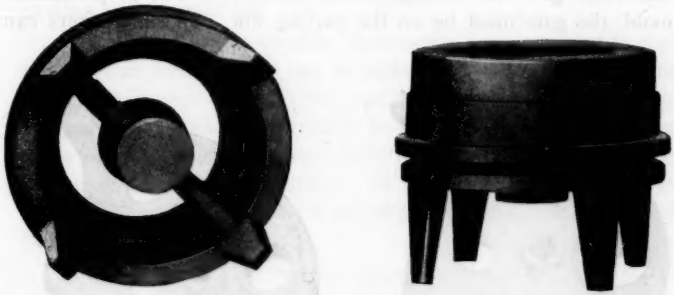

FIG. 1. GASOLENE PUMP FOOT VALVE WHICH MUST NOT LEAK—MAKING THE CENTER BOSS FREE FROM SINKS REQUIRES SPECIAL PRECAUTIONS TO FEED THE CRYSTALLIZATION SHRINKAGE THROUGH THE THIN RIBS SUPPORTING THE BOSS

There again, the failure to eject the casting properly or at the proper time shows itself on the surface in the form of cracks.

If the mold is not properly vented, sections will not fill. This defect also is evident.

As the molds are usually hand poured and as there is no external pressure on the metal, the flow of the molten metal is smooth and there is little likelihood of entrapping air in the metal.

All of these factors must be taken care of in the design of the molds and it is in this design that the greatest skill is shown. The designer has thermal and metallurgical problems as well as mechanical ones, and in the solution of these, considerable ability and experience is required. A study of Figs. 1 to 8 will indicate

some of the problems to be met in this permanent mold design work.

It seems so simple, but the making of good permanent mold castings is a snare and a delusion to those who do not fully comprehend the fundamental principles. Right here it might be well to compare permanent mold practice with sand casting practice.

Sand Castings and Permanent Mold Castings

To take care of crystallization shrinkage, the sand founder can often gate the castings where he desires, but in permanent mold, the gate must be on the parting line. In sand, risers can

FIG. 2. DISHWASHING MACHINE CONTROL PANEL IN WHICH SATISFACTORY APPEARANCE CAN BE OBTAINED ONLY BY VENTING

usually be put where the need exists, but the permanent mold often will not permit this. A chill is a God-send to the sand founder—it often solves the difficult casting problem, but to what can the permanent mold caster look for the same help? He can and often does vary the thickness of his mold, but a thin mold, without special precautions, will warp, and one of varying sections warps badly. Some manufacturers have resorted to inserts of a metal with a higher heat conductivity than iron to act as

a chill does in sand, but this expedient is none too satisfactory, because the insert is eroded, works loose or shows a bad mark on the casting. And often it is not a solution of the trouble.

The coefficient of thermal expansion of aluminum alloys is a factor of concern. For aluminum alloys, this coefficient is just about twice that of cast iron. Sand foundrymen complain about castings cracking when the sand cores are a little hard; just imagine permanent mold problems of using solid metal cores. It is apparent that these metal cores must be pulled at just the right time, not too soon or the metal will run, and not too late or the casting will be cracked.

In addition to this trouble, there is the frequent need to make the cores in parts so they can be pulled. A casting with a flange extending inward requires the use of five part cores and more complicated shapes require cores in seven parts or more. These cores must be kept in good conditions to avoid fins and flash where they fit with one another. In sand practice, undercuts and such shapes which cause the permanent mold designer to really think, are quite simple.

Venting is another consideration for the metal molder. In sand practice, the use of an open sand or the use of a vent wire to open up the sand often relieves any anxiety on this score, while in permanent mold, special arrangements must be made to get rid of the air in the mold cavity. This is easy on the parting faces of the mold, but it is surprising how ineffective this opportunity seems in a somewhat complicated part. The special vents must be arranged—and what is worse, they must be kept open.

The writer once heard of a permanent mold founder trying to make a flat plate seven inches in diameter. He cast this just as a sand foundry would cast it, laying it down flat. Before he got a good casting, he had to put in twenty-four vent pins over the face of the casting and the mold looked like a porcupine. This manufacturer should have entirely forgotten any sand cast practice and should have made this plate vertically, but that did not occur to him until the experimental work with the mold had cost him several hundred dollars.

In sand cast practice, a molder will make up a number of molds and then pour off the lot of them at one time; the melter

only has to bring his metal up to temperature and pour off rapidly. In permanent mold work, however, the metal must be brought up to temperature and kept at temperature for a period of one hour to nine hours, and it is believed that the possible range of temperature of the metal in permanent mold work is much less than in sand cast practice. This means closer supervision of metal melting in permanent mold work and also greater expense.

While speaking of expense, it might be well to point out that the usual practice in permanent mold work is for the foundry to pay for the repair and renewal of the mold equipment, while in sand cast practice the customer is supposed to furnish suitable

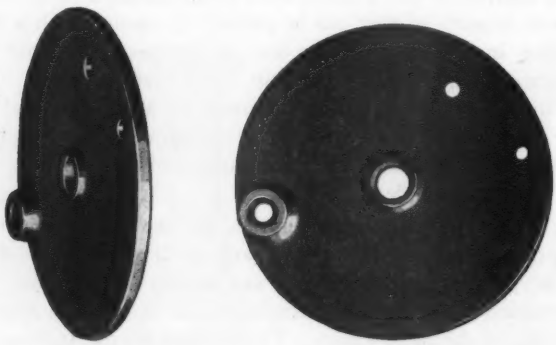

FIG. 3. COVER PLATE WHICH IS DIFFICULT TO MAKE WHEN POURED FLAT BUT COMPARATIVELY EASY WHEN POURED VERTICALLY

pattern equipment and the customer pays for the maintenance of the equipment.

When a permanent mold fails to produce castings in accordance with the customer's prints, it is up to the foundry; often a sand foundry can use the pattern equipment as an alibi for unsatisfactory castings.

Another comparison should be seriously considered and that is the working conditions in the foundry. It is true that a sand foundry often is dirty and the presence of the sand seems to have an effect on the management to cause them to permit even the

windows to remain dirty, but there is no excuse for a permanent mold shop to be dirty.

However, this advantage of adequate light and cleanliness is largely overcome by the fact that the permanent mold operator is subjected to much greater heat. All day long he works over a hot mold. He has a holding furnace at his back and the hot castings on one side; these give off a great amount of heat, so that artificial ventilation is practically a necessity in a permanent mold foundry, particularly in warmer weather, which is another item of expense.

Thus there is a considerable difference in the two processes of making castings, and in the equipment. In another respect, the practice differs. It is questioned if the purchaser of castings expects as perfect a product in sand casting as he does in permanent mold, and therefore the inspection of the permanent mold castings must be more close.

Fortunately for the user, however, the faults in permanent mold castings are easily detected; these faults are almost invariably evident on the surface of the casting, so the user can depend upon a solid section if the surface is good. With permanent mold castings, there is no need of the precaution to "Save the surface and you save all," as they are solid all the way through. There is not a great deal of difference in the appearance or strength of the metal at the surface and in the center of the casting.

The molds are kept relatively hot while in operation, but considerably below the melting point of aluminum alloys so that the moderate chilling of the permanent mold bestows on the casting a dense fine grain, causing an increase in tensile strength, elongation and hardness.

The fine grain also betters the polishing qualities of the casting.

Some of the advantages of the permanent mold casting can be listed as follows:

1. Freedom from blow holes and porosity.
2. Dense homogeneous, fine grain.

3. Freedom from black spots, pin holes and "carbon tails" when polished.

4. Greater strength, greater elongation and greater resistance to impact.

5. Relative accuracy in dimension.

6. Smooth bright surfaces.

Because permanent mold castings, well made, have the six advantages listed above, and because their physical properties are dependable, they have become increasingly popular with users of castings. But there is a somewhat definite field of application for their use and there are limitations in the process.

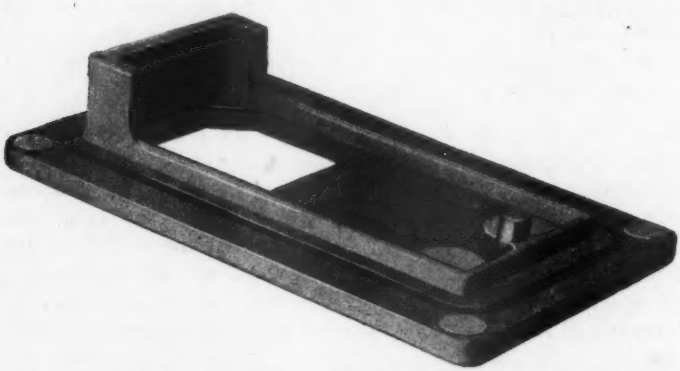

FIG. 4. WATER TIGHT PLATE—THE SMOOTHNESS OF THE CASTING PERMITTED ENAMELING WITHOUT GRINDING AND RELATIVE ACCURACY OF DIMENSION SAVED COSTLY MACHINING OPERATIONS OF MILLING OUT THE GROOVE FOR A RUBBER GASKET

In comparing permanent mold castings with sand castings, we believe a few paragraphs from a paper by S. L. Archbutt of the National Physical Laboratory of Teddington, England, read March 11, 1925, at a meeting of the British Institute of Metals, will be of interest.

"Aluminum alloys cast in sand are in general inferior in mechanical properties and general soundness to corresponding castings made in metal or chill molds. The slower rate of

solidification which occurs in a sand mold produces a course grain which is in itself detrimental to mechanical properties. These defects are, however, usually accentuated by general unsoundness, commonly of the type known as 'pin holing.'

"The pin holes are small cavities more or less spherical in shape, fairly uniformly disseminated through the body of the casting; they are revealed on machining.

"Coarseness of grain and pin holing are accentuated in sand castings by high pouring temperatures. If melting and pouring temperatures are kept low, considerable improvement can be effected in respect to these defects.

"Under the most carefully controlled conditions, however, employing normal foundry practice and treatment of melts, it has not been found possible at the laboratory to effect more than a certain degree of improvement in unsoundness.

"Using the 1-inch diameter bar as a standard form of casting, cold dry sand molds, melting temperatures not exceeding 730 degrees Cent., pouring temperatures as low as 650 degrees Cent., and ample risers and runners, the general order of density of cast bars of aluminum alloy "Y" which is copper 4 per cent, nickel 2 per cent, magnesium 1.5 per cent, balance aluminum (with the skin on) is 2.735, with an occasional value as high as 2.750. These values are to be compared with 2.780 for corresponding bars cast in metal molds.

"The average tensile properties of these two classes of bars in the cast conditions are as follows:

	Sand cast	Metal cast
Density with skin on	2.735	2.798
Yield stress, tons per square inch	.....	11.4
Ultimate stress, tons per square inch	10.5	14.8
Elongation per cent on 2 inches	.5	2.5

"The fact that pin holing can be eliminated in castings of normal thickness by employing metal molds is well known at the National Physical Laboratory and probably in most aluminum foundries."

Pressure Die Castings and Permanent Mold Castings

In the pressure die cast process, a cavity in a metal mold is filled with molten metal under pressure through a thin gate. The gate is thin so as to reduce the turbulence of the molten metal in entering the cavity, and to allow a time interval during which the air in the cavity can be forced out through the vents.

The result is that after the cavity is filled with molten metal, the small gate freezes and cuts off the source of hot metal. The skin of the casting next to the cold mold freezes and the solidification shrinkage of about 7 per cent is fed from the center of the casting or from heavier sections which are still molten.

The former chief engineer of a prominent pressure die casting manufacturer explained this condition quite well in an address before the Detroit branch of the Society of Automotive Engineers in March, 1925, as follows: "Porosity is an inherent feature of commercial high pressure die castings. At first it was believed that this was due to the presence of air. The vacuum process was introduced so that the air was drawn out of the die cavity before the metal entered. Even if it were possible to maintain a vacuum under practical working condition, this method does not offer the complete remedy. Practically the same results may be obtained without a vacuum, if the proper size and location of the gate and vent grooves are carefully considered.

"There are two other causes for porosity, namely, uneven chilling of the metal and drossy, sluggish metal. To illustrate the first cause, consider a die casting gated so that the metal must travel through a thin section to reach a heavy boss.

"Normally the boss will solidify last, but since the thin section between it and the gate is already frozen, it has nothing to draw from to satisfy its natural shrinkage, and the difference is made up by a void or hole in the center. This emphasizes the importance of proper distribution of water channels in the die.

"The second cause is self-evident, for a die casting cannot have a cleaner structure than the original alloy. If too many impurities are in the alloy, its flow becomes sluggish and it chills before the shrinkage is satisfied even in uniform walls. However, the outer crust is so much greater in density and strength

that it more than compensates for the porous structure in the center of the wall."

The skin of the pressure die casting is of a very close dense grain and therefore if this skin is not taken off in machining or in polishing, the presence of the voids in the center of the casting does not affect the utility of the part when the part is not subjected to strains.

But this porosity must weaken the section materially, and therefore it is felt that continued work will be applied to the pressure die cast process to eliminate this porosity, or parts subject to severe strains should be made in permanent mold.

Field of Application of the Three Types of Aluminum Alloy Castings

From this description of a sand casting, a pressure die casting and a permanent mold casting, one can somewhat outline the fields of application of each of the three products.

A sand casting is used in parts having difficult coring, such as automobile intake manifolds, cylinder blocks, vacuum cleaner fan cases and nozzles. Likewise, a sand casting is used in parts of large dimension such as automobile crank cases, and oil pans, though foreign manufacturers are now making some of the smaller crank cases in permanent mold. A sand casting is often more economical when the quantity required is small, because of the smaller cost of pattern equipment.

It should be remembered that the sand cast process is well known and up to about 1912 all aluminum casting production in this country was done in this process. The other processes using metal molds since then have taken business away from the sand foundries. There are yet a great many parts made as sand castings which might better and more economically be made in other processes, and it is to be expected that this diversion of business will continue as the other processes become better known.

The aluminum pressure die casting is an offspring of the tin, lead and zinc base casting industry, and represents a development made possible by the production of special steels to withstand

the effects of the higher temperatures of aluminum alloys, as well as a development of suitable die casting machines. The product is especially applicable for use where an accuracy of dimension within limits of .0025 to .004 inches per linear inch of dimension will save machine work. Small motor brush holders cannot be made as economically in any other process. However,

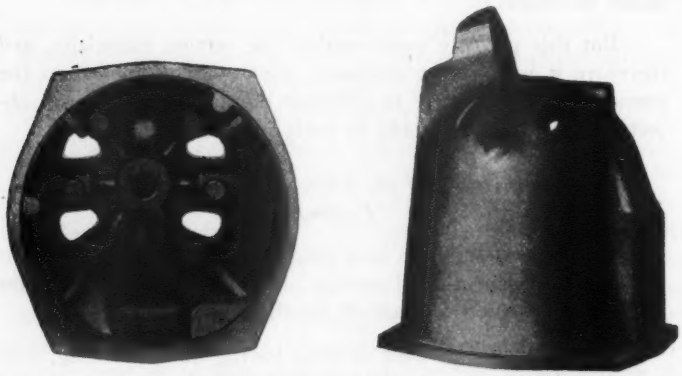

FIG. 5. VACUUM CLEANER MOTOR HOUSING—THE CASTINGS FIT ACCURATELY THE JIGS AND FIXTURES FOR THE MACHINE WORK NECESSARY TO ATTAIN PRECISE ASSEMBLY DIMENSIONS AND THE DENSE FINE GRAIN TAKES AN EXCELLENT POLISH

as is often the case, the pressure cast limits of accuracy are not close enough for use without machine work, then pressure casting has then lost its chief advantage.

The finish of the die casting is often quite good and it is sufficiently smooth to take paint or enamel without any buffing operation. Check protector and adding machine housings are good examples. However, if the die cast part is to be polished, care must be taken not to grind too much below the natural dense surface, thereby reaching the porous structure usually present toward the center of the wall.

The process is particularly useful in producing small and more complicated parts such as spark and gasolene control levers, magneto housings, speedometers, etc., as well as being well

adapted to making large covers and housings in which a saving in wall thickness means a saving in weight and cost.

The pressure die cast process is applicable primarily to large production, because of the expense of the die equipment. The cost of this equipment is usually about three times the cost of the sand cast metal pattern equipment and about ½ to ⅓ more than permanent mold equipment. But with this equipment, the production per day is materially higher than in sand castings and somewhat higher than in permanent mold, so the cost of equipment per casting per day in pressure is usually about the same as in the other processes. In other words, to produce as many castings per day in sand as can be produced from one pressure die would require about three pattern equipments.

The permanent mold process is a later commercial development than the sand cast process, though the idea is even older than casting molten metal in sand. It is natural, therefore, that certain types of castings have been taken out of sand or pressure die cast production and put into permanent mold when the superior properties of the permanent mold castings are appreciated.

For instance, vacuum cleaner motor housings were made in sand; some manufacturers adopted pressure die castings, but on account of the superior polishing and machining qualities, many of these housings now have been transferred from the sand and from pressure die production to permanent mold production.

Another instance of this change to acquire better physical properties is the one from sand cast production of automobile steering wheel spiders to pressure die cast and later to permanent mold production. This change to permanent mold is just starting, but it is natural to expect the transfer to continue as permanent mold castings offer greater strength, greater ductility and comparative freedom from polishing troubles.

Just as the pressure die cast process broadened the market for aluminum castings by saving machine work, so the permanent mold process is broadening the market by giving the user a wide range of dependable physical properties in the aluminum alloy castings.

Aluminum alloys with a softness of type metal, a strength greater than average cast iron and high ductility are at one end of

the series, while alloys with a hardness of bell metal bronze, a high strength and with a little more ductility than cast iron are at the other end.

The soft alloys will readily rivet over or spin over; they can easily be welded to sheet aluminum while the hard alloys afford good bearings and have good wearing qualities.

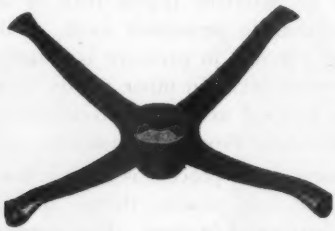

FIG. 6. STEERING WHEEL SPIDER WHICH IN PERMANENT MOLD SAVES ALL MACHINE WORK EXCEPT THE REAMING OF THE TAPERED CENTER HOLE AND THE CUTTING OF THE KEY WAY—THE CASTING FREE FROM BLOW HOLES IS STRONG AND DEPENDABLE

For instance, it is seriously doubted if aluminum pistons would be used so generally today if it were not for the permanent mold process and it is not believed that automobile valve tappet guides have ever been made in any other process.

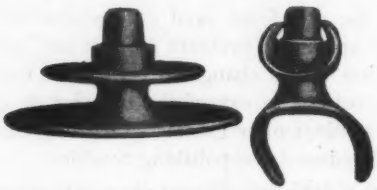

FIG. 7. PERCOLATOR BASE OF A SOFT ALLOY AS CAST AND AFTER BENDING COLD—THE ALLOY WILL READILY RIVET OVER OR SPIN OVER AND IS OF A COMPOSITION WHICH CAN EASILY BE WELDED TO PURE ALUMINUM SHEET

So it is seen that the permanent mold process is distinctly different from the other processes of making castings and the produce has different qualities.

Permanent mold castings are singularly free from blow holes and porosity, and the surface, no matter how much material is taken off in machining or polishing, is free from pin holes, black spots and other such imperfections. They are therefore preferred for castings which must be polished. The castings are dense and have a particularly fine grain; therefore the castings have a greater strength and a greater elongation than castings made of

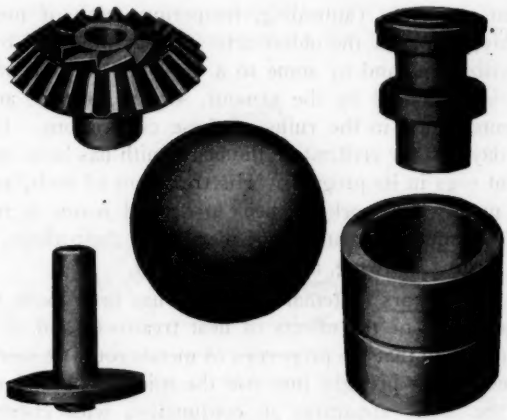

FIG. 8. CASTINGS OF A HARD ALLOY WHICH RESISTS WEAR AND WHICH IS GOOD BEARING METAL

the same alloys in either of the other processes. In physical properties, permanent mold castings are dependable.

Permanent mold castings have a smooth bright surface and they are relatively accurate in dimension. They, therefore, have a certain finished appearance as cast, somewhat similar to pressure die casting when made from a new die, and permanent mold castings always have this same smooth finish, as the molds do not surface crack with use.

Therefore there is a distinct field of application for the permanent mold casting process.

The Effect of Heat Treatment on the Properties and Microstructures of Grey Cast Iron and Semi-Steel*

By O. W. Potter,** *Minneapolis, Minn.*

Heat treatment (annealing, tempering, etc.) of metals and their alloys is one of the oldest arts. It was practiced by all ancient civilizations and by some to a very high degree of perfection as is evidenced by the armour, swords, spears, and other implements found in the ruins of these civilizations. From the earliest days of our civilization the blacksmith has been one of the important cogs in its progress. His treatment of tools, and handling of metals and working them to desired forms is really the basis of our modern treatment of metals and their alloys, e.g., the rolling, forging, drawing, and heat treatment.

In recent years systematic research has been made to determine the causes of the effects of heat treatment and of hot and cold working, so that the properties of metals could be more closely controlled. This brought into use the microscope and more recently, the x-ray apparatus in conjunction with chemical and physical analysis to correlate all these properties.

The iron carbon series of alloys is one of the most complicated, yet much research has been done to determine the properties and the effect of heat treatment and impurities. By far the greater amount of investigation has been done on the steel side of the series. The complexity of the composition of cast irons (including semi-steel) and the difficulty of controlling compositions during melting have no doubt been factors in hindering extensive investigations. The general indifference of the grey iron foundrymen to foster research for the study of ways and means to improve the qualities of cast iron has also been a hindering factor to the study of the effects of heat treatment. It has been generally thought that cast iron being a weak, brittle material, comparatively

*Presented on behalf of the Twin City Foundrymen's Association.
**University of Minnesota.

cheap in cost of production could not have its properties improved. The late eminent authority on steels and cast irons, Doctor Howe, stated many years ago that he believed the possibilities of improving the properties of grey cast iron by heat treatment were even greater than they were for steel. We find today that through stress of production demanding ease of machinability and uniform properties that heat treatment has been resorted to with considerable success.

Grey cast iron has two properties, the control of which has always been one of the foundrymen's big problems. They are

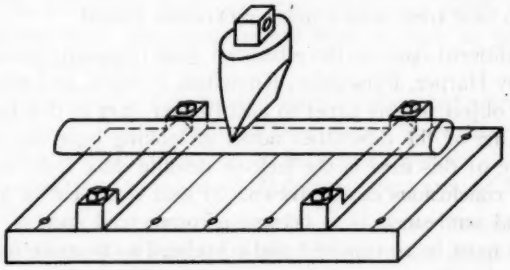

FIG. 1—SKETCH OF SPECIAL APPARATUS FOR TRANSVERSE TESTING USED WITH AMSLER WIRE TESTING MACHINE—THE MACHINE WAS OPERATED IN COMPRESSION WITH THE APPARATUS SKETCHED ABOVE

the hardness and dimensional changes under repeated heating and cooling. To produce uniform hardness and eliminate massive cementite from grey iron is the constant endeavor of every foundryman, manufacturing castings which must be machined. Cementite is extremely hard and soon ruins the best cutting tools. The ideal condition is to have grey cast iron wholly in a pearlitic condition (this eliminates all massive cementite). This is difficult to obtain under ordinary casting conditions because of such influencing factors as casting temperature, rate of cooling, chemical composition carbon content, amount of impurities present, design of casting, etc. It has been found by some manufacturers that the only real satisfactory method of getting uniform hardness and the elimination of massive cementite is to heat treat (anneal) the castings.

For many years the peculiar growth property of grey cast iron has been known. Outerbridge[1] did some extensive work in the nineties on this property and it has been observed since by many others. In 1924 Bradley Stoughton[2] reported the results of the Schaap process of heat treatment. One of the important findings reported was the elimination of growth under proper heat treatment. If this is correct then many problems of the manufacture of castings which must be machined and subjected to high temperatures either continuously or intermittently will be lessened. Also the warpage due to casting strains is considerable in cast irons. The ageing of castings has been practiced for many years by some manufacturers to overcome this difficulty, but recent practice is to heat treat with a low temperature anneal.

Additional data on the effects of heat treatment has been reported by Harper, Piowarsky, Knowlton, Forsyth, and others, and it is the object of this paper to add further data to this important field. One of the difficulties noted in looking over the available literature of this field is the lack of definite data from which intelligent conclusions can be drawn. If heat treatment of grey cast irons and semi-steels is to become a commercial success, data on research must be so reported and correlated as to make it possible to determine the proper heat treatment necessary for the production and control of the desirable properties. This involves proper chemical analysis, temperature of treatment, rate of heating and cooling, media during treatment, etc.

Specimens and Their Preparation

The material used in this investigation was regular run cast grey iron and semi-steel used in a commercial plant. The charges consisted of 50 percent Northern pig iron and 50 percent machinery scrap iron melted with a good grade of foundry coke. The semi-steel bars were made from the same materials with 15 to 25 percent steel added to the charge.

The ordinary arbitration test bar 1¼ inch diameter and 15 inches long cast according to the recommendations of the American Foundrymen's Association was used. These bars were tested

[1]Journal Iron and Steel Inst., Vol. 83, No. 1, p. 643.
[2]Iron Age, January 3, 1924.

in transverse strength with 12 inch supports with the load at the middle. One half of the broken bar was then drilled to obtain samples for chemical analysis and the other half was used as follows:

1. A piece about ½ inch wide was cut off the bar and polished for microscopic examination.

2. One end of the bar was then ground smooth and tested for hardness with the Shore Scleroscope and the Brinell machine. Five readings were taken with the Scleroscope and two with the Brinell to get a mean reading.

3. Twelve of these half bars were used for tensile test.

4. The remaining bars were then cut in two pieces lengthwise, and machined into small round bars ½ inch in diameter by about 7 inches long.

5. The bars to be heat treated were then marked with 4 sets of 5 inch gauge lengths each. These marks were first center punched, then drilled with a No. 50 drill to a depth of about 1/16 inch. The markings were spaced 90 degrees apart around the bar.

6. All bars were measured with a micrometer for diameter and the gauge marks measured with a Berry strain gauge.

7. Bars representing one of each set were taken and arranged into groups and heat treated as follows:

T-1. Heated to 1600 degrees Fahr. (870 degrees Cent.) and held for 3 hours, cooled to black in furnace in 15 minutes, and then removed from furnace and air cooled.

T-2. Heated to 1450 degrees Fahr. (790 degrees Cent.) and quenched in cold water.

T-3. Heated to 1370 degrees Fahr. (735 degrees Cent.) and quenched in cold water. (Below critical.)

T-4. Heated to 1600 degrees Fahr. (870 degrees Cent.) and cooled in furnace.

T-5. Heated to 1370 degrees Fahr. (735 degrees Cent.) and quenched in oil. (Below critical.)

T-6. Heated to 1450 degrees Fahr. (790 degrees Cent.) and quenched in oil.

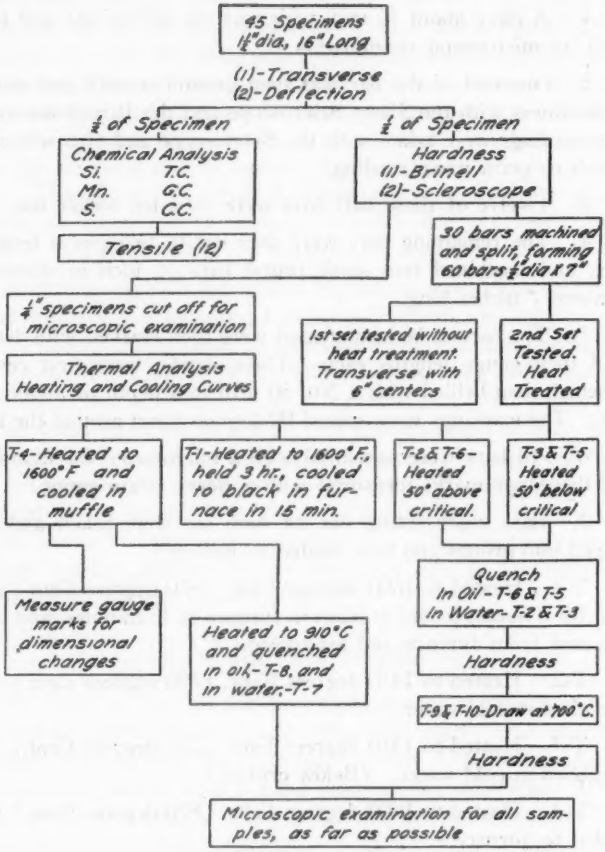
45 Specimens 1½" dia., 16" Long
(1)-Transverse
(2)-Deflection
½ of Specimen
½ of Specimen
Chemical Analysis
Si. T.C.
Mn. G.C.
S. C.C.
Hardness
(1)-Brinell
(2)-Scleroscope
Tensile (12)
30 bars machined and split, forming 60 bars ½ dia X 7"
½" specimens cut off for microscopic examination
Thermal Analysis Heating and Cooling Curves
1st set tested without heat treatment. Transverse with 6" centers
2nd Set Tested. Heat Treated
T-4-Heated to 1600°F and cooled in muffle
T-1-Heated to 1600°F, held 3 hr., cooled to black in furnace in 15 min.
T-2 & T-6-Heated 50° above critical.
T-3 & T-5 Heated 50° below critical
Measure gauge marks for dimensional changes
Heated to 910°C and quenched in oil,-T-8, and in water,-T-7
Quench In Oil - T-6 & T-5 In Water - T-2 & T-3
Hardness
T-9 & T-10-Draw at 700°C.
Hardness
Microscopic examination for all samples, as far as possible

FIG. 2—DIAGRAMATIC OUTLINE OF INVESTIGATION

T-7. Heated to 1600 degrees Fahr. (870 degrees Cent.) and cooled slowly in furnace, reheated to 1670 degrees Fahr. (910 degrees Cent.) and quenched in water.

T-8. Heated to 1600 degrees Fahr. (870 degrees Cent.) and cooled slowly in furnace, reheated to 1670 degrees Fahr. (910 degrees Cent.) and quenched in oil.

T-9. Heated to 1450 degrees Fahr. (790 degrees Cent.), quenched in water and drawn to 1292 degrees Fahr. (700 degrees Cent.).

T-10. Heated to 1450 degrees Fahr. (790 degrees Cent.), quenched in oil, and drawn to 1292 degrees Fahr. (700 degrees Cent.).

8. To determine dimensional changes the gauge marks on bars were measured immediately after heat treatment.

Table 1

CHEMICAL ANALYSIS

Spec. No.	Date Cast	Si.	Mn.	T.C.	G.C.	C.C.	S.
1 C. I.	11-25-24	2.18	.52	3.23	2.58	.65	
2 S. S.	11-25-24	2.09	.58	3.11	2.51	.60	
3 S. S.	11-26-24	1.95	.59	3.03	2.34	.69	
4 C. I.	11-26-24	2.28	.55	3.35	2.77	.58	
5 S. S.	11-28-24	2.02	.54	3.07	2.43	.64	.085
6 C. I.	12- 1-24	2.21	.49				.106
7 S. S.	12- 1-24	2.06	.54	3.28	2.58	.79	.082
8 S. S.	12- 2-24	2.16	.55				.090
9 C. I.	12- 2-24	2.37	.52	3.15	2.75	.40	.092
10 S. S.	12- 3-24	1.87	.53	3.12			.094
11 C. I.	12- 3-24	2.18	.51	3.33	2.53	.80	.101
12 C. I.	12- 4-24	2.23	.52	3.42	2.53	.89	.099
13 S. S.	12- 4-24	1.82	.51	3.20	2.23	.97	.093
14 S. S.	12- 5-24	1.82	.49	3.19	2.28	.91	.092
15 C. I.	12- 5-24	2.11	.48	3.32	2.43	.79	.091
16 S. S. (Cyl.)	12-16-24	1.40	.46	3.18	2.32	.81	.114
17 C. I.	12-12-24	2.44	.59	3.41	2.90	.51	.090
18 S. S.	12-12-24	1.99	.49	3.17	2.26	.91	.090
19 C. I.	12-13-24	2.44	.54	3.42	2.78	.64	.088
20 C. I.	12-15-24	2.25	.54	3.49	2.53	.96	.091
21 S. S.	12-15-24	1.95	.52	3.19	2.20	.99	.094
22 S. S.	12-16-24	1.85	.46	3.10	2.12	.98	.085
23 C. I.	12-16-24	2.09	.52	3.38	2.51	.87	.100
24 S. S.	12-17-24	1.78	.55	3.04			.088
25 C. I.	12-17-24	2.16	.55	3.23	2.30	.93	.108
26 C. I.	12-18-24	2.09		3.23	2.51	.74	
27 S. S.	12-18-24	1.92	.49	3.05			.080
28 C. I.	12-19-24	2.11	.46	3.15	2.57	.58	.105
29 S. S.	12-19-24	1.92	.55	2.90			.100
30 C. I.	12-20-24	2.16	.54	3.23	2.57	.66	.114
31 S. S.	12-20-24	1.87	.52	3.23	2.43	.81	.097
32 S. S. (Cyl.)	12-20-24	1.40	.46	3.22	2.53	.69	.096
33 S. S.	12-22-24	1.92	.53	3.22	2.87	.46	.071
34 C. I.	12-22-24	1.99	.55	3.44	2.66	.78	.098
35 C. I.	12-23-24	2.11	.58	3.41	2.39	1.02	.107
36 S. S.	12-23-24	1.82	.66	3.22	2.47	.75	.088
38 S. S. (Cyl.)	11-29-24	1.97	.49	3.15	2.44	.71	.089
44 C. I.	11-28-24	2.58	.51	3.46	2.84	.62	.081
45 C. I.	11-29-24	2.51	.52	3.42	2.70	.72	.106

9. All bars, both heat treated and untreated were then tested transversely on the specially prepared transverse testing apparatus shown in Fig. 1.

10. The pieces resulting from transverse test were cut to length and then tested in a Charpy impact machine without notching.

11. The heat treated bars were again tested for both the Scleroscope and Brinell hardnesses.

12. Several representative pieces were also run in thermal analysis to determine the critical points.

An outline of this investigation is shown in diagrammatic form in Fig. 2 which follows, and a list of specimens and their numbers, dates cast, description and chemical analyses is given in Table 1.

Discussion of Carbon

Comparison of Carbon Content of Grey Cast Iron and Semi-steel: Upon examining the chemical analysis of the specimens one of the first noticeable tendencies is the fact that practically every

Table 2

CARBON CONTENT BEFORE AND AFTER HEAT TREATMENT

	Untreated			Heat Treated					
				T-1. Heat to 870° C. Cooled Rapidly			T-3. Heat to 735° C. Quench in Water		
Spec. No.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.	T. C.	G. C.	C. C.
17 C. I.	3.41	2.90	.51	3.36	3.03	.33			
20 C. I.	3.49	2.53	.96	3.24	2.95	.29			
33 S. S.	3.22	2.87	.46		3.02				
40				3.14	3.27				
42 S. S.				3.08	2.92	.16			
43 S. S.							2.61	1.98	.63
44 C. I.							2.77	2.66	.11

	Untreated			T-4. Heat to 870° C. Cool in Furnace			T-5. Heat to 735° C. Quench in Oil		
Spec. No.	T. C.	G. C.	C. C.	T. C.	G. C.	T. C.	T. C.	G. C.	C. C.
9 C. I.	2.15	2.75	.40	3.24	3.36	0.0			
12 C. I.	3.42	2.53	.89	3.04	3.16	0.0			
15 C. I.	3.32	2.43	.89	3.36	3.46	0.0			
21 S. S.	3.19	2.20	.99	3.06	3.10	0.0			
28 C. I.	3.15	2.57	.58	3.06	3.24	0.0			
31 S. S.	3.23	2.43	.81	3.38	3.42	0.0			
(38) 41 S. S.	3.15	2.44	.71	3.10	3.02	0.0			
42 S. S.				3.04	2.90	0.0			
45 C. I.	3.42	2.70	.72	3.14	3.34	0.0			
11 C. I.	3.33	2.53	.80				3.12	2.80	.32
35 C. I.	3.41	2.39	1.02				2.76	2.76	0.0

day's run shows a lower total carbon content in the semi-steel than in the grey iron. This confirms definitely the opinion of many investigators that properly made semi-steel has the lower total carbon content. Whether the combined or graphitic carbon is reduced does not show up so clearly, and no definite tendency seems to be apparent. Analyses of 15 samples of semi-steel give an average of .78 percent combined carbon while for 18 samples of grey iron the average was .73 percent.

Influence of Heat Treatment on Carbon: The results of the analyses of the specimens for total, combined, and graphitic carbon after heat treatment are shown in Table 2. A study of these results shows the following tendencies:

1. When heated above the critical point and cooled rapidly (not quenched), as in heat treatment T-1, there is practically no change in total carbon, but the combined carbon has been greatly reduced.

2. When heated above the critical point and cooled slowly in the furnace (T-4) there seems to be no change in total carbon with the possible exception of extremely high silicon irons, but the combined carbon has been completely decomposed.

3. Under heat treatment T-3 where the specimens were quenched in water from just below the critical point there was a decided tendency to oxidize some of the carbon.

4. Under heat treatment T-5 where the specimens were quenched in oil from just below the critical point there was also a tendency to oxidize some of the carbon. In addition the amount of combined carbon content was reduced.

Because of the hardness of the specimens quenched in both water and oil from above the critical point (T-2 and T-6) no drillings were obtained and therefore no carbons were determined. The microstructures and hardness of these specimens clearly show a decided increase in the combined carbon content. Lack of time prevented carbon determinations after heat treatments T-7, T-8, T-9, and T-10.

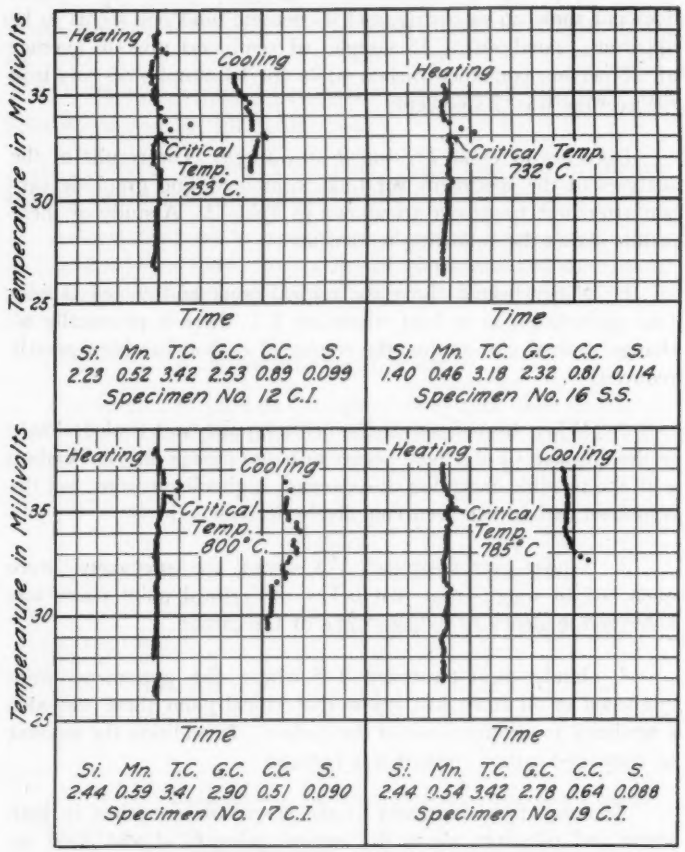

FIG. 8—ANALYSES OF SPECIMENS AND HEATING AND COOLING GRAPHS

Thermal Analysis

Thermal analyses were run on four samples of widely varying chemical compositions to determine the critical points. Values were recorded for the inverse rate type of curve, that is, time was recorded for equal advances in temperature ($dt/d\Theta$). An electric furnace with noble metal heating element and a Leeds Northrup potentiometer with a galvanometer indicator was used. The analyses of specimens and graphs are as shown in Fig. 3.

The Ac point seemed to show up quite distinctly but the Ar point was rather indeterminate. Since Nos. 17 and 19 were exceptionally high in silicon for heat treatment the average of the results of specimens Nos. 12 and 16 or 735 degrees Cent. was considered about the critical point for most of the specimens under consideration in this investigation.

Discussion of Critical Range of Cast Grey Iron

The wide variance of the data available on critical temperature of grey cast iron and the fact that so little information is at hand as to the kind of material, chemical analysis, etc., make it doubly difficult to draw intelligent conclusions. The carbon content and the content of other impurities is quite essential to arrive at such conclusions.

According to all the data available the lower critical always occurs above 700 degrees Cent. From those data giving combined carbon analyses the critical point seems to follow somewhat that of steel of the same carbon content as combined carbon in the grey iron. The effect of silicon in steel according to Hoyt and others is to eliminate the Ac_1 and Ac_3 and to raise the Ac_2 points. According to Vigorous[3] the addition of silicon to steel up to 3 percent has the effect of raising the Ac_2 point 28 degrees Cent. per 1 percent silicon. Manganese has the opposite effect to silicon and tends to lower the critical at the rate of about 25 degrees Cent. per 1 percent manganese. Calculating the Ac_2 point on this basis we get the values listed in Table 3. These calculated values check very well and lead one to believe the critical temperature for cast iron can be roughly calculated from the combined carbon, silicon, and manganese contents.

[3]Ibid, 1918. Vol. 156, p. 1374.

As a matter of comparison a number of commercial heat treating temperatures are given at the end of this table. It is impossible to say from the data available whether or not these heat treating temperatures were selected as a result of thermal analysis. However, it is known that in the case of some companies a thermal

Table 3

TABLE OF CRITICAL TEMPERATURES

Authority:	Piowarsky	Wust and Peterson		W. R. Bean
Analysis:		Chemical Analysis		
Si	2.95	2.25	1.14	.87
Mn.	.63	.60		
P.	.102	.090		
S.	.086	.055		
T. C.	3.18	2.48	3.96	2.58
G. C.	2.49			
C. C.	.69			
Critical Points:		Critical Temperatures		
Ac				
°C	810–825	800–805		763
°F	1490–1517	1472–1481		1405
Ar				
°C	725–750	735–740	740–750	746
°F	1357–1382	1355–1364	1364–1382	1375
		Calculated Critical Temperatures		
Ac2				
°C	732	739	713	737
°F	1350	1362	1315	1359

Authority	Forsyth			O. W. Potter			
				No. 12	No. 16	No. 17	No. 19
Si.	2.28	2.25	2.11	2.23	1.40	2.44	2.44
Mn.	.52	.46	.55	.52	.46	.59	.54
P.	.624	.43	.392				
S.	.003	.09	.079	.099	.114	.09	.088
T. C.	3.19	3.19	3.25	3.42	3.18	3.41	3.42
G. C.	2.96	2.68	2.34	2.53	2.32	2.90	2.78
C. C.	.21	.51	.71	.89	.81	.51	.64
Critical Points:				Critical Temperatures			
Ac							
°C	765–790	796–804	791–795	732	732	800	785
°F	1409–1454	1465–1479	1456–1463	1350	1350	1472	1445
Ar							
°C	740–750	751–755	746–755				
°F	1364–1382	1384–1391	1375–1391				
				Calculated Critical Temperatures			
Ac2							
°C	706	735	735	670	693	732	717
°F	1313	1351	1351	1238	1279	1349	1323

Authority:	Hubmobile Co.	Arrow Head Steel Products Co.	Schaap	Harper	H. E. Diller	Dr. E. Schuz
Commercial Heat Treating Temperatures:						
°C	715	830	870	650–760	550–800	700–800
°F	1325	1525	1600	1200–1400	1025–1472	1292–1472

Authority:	Hatfield	Studebaker Corp.
Commercial Heat Treating Temperatures:		
°C	900	760–815
°F	1652	1400–1500

analysis by such a method as the Hump process is used to determine the proper annealing temperature for cast iron.

In order to show more clearly the relation of the observed critical temperatures and the critical temperatures as calculated from the chemical compositions the results have been plotted in Fig. 4 in which the critical temperatures are plotted against the combined carbon contents. Curve I represents observed values and curve II the calculated values. It will be noted that the observed values are somewhat above Ac_2 while the calculated values fall

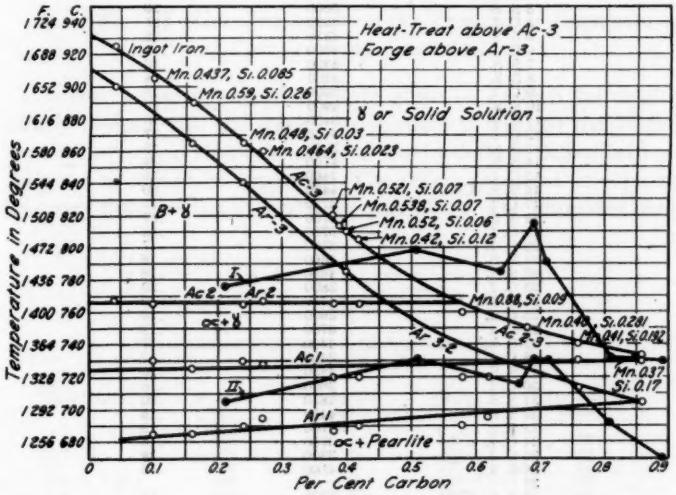

FIG. 4—CRITICAL TEMPERATURE CURVES PLOTTED AGAINST COMBINED CARBON CONTENTS*

more nearly on the Ac_1 line and an approximate figure may be set at 730 degrees Cent.

Since the manganese content is usually low and rather constant, this suggests the possibility of the critical temperature being largely a function of the silicon content. The graph of Fig. 5 was plotted silicon content against critical temperatures and discarding the two results on the 730 line the points show this ten-

*Diagram by R. L. Dowell.

dency. It is the opinion of the author that a very definite critical temperature line could be determined on this basis with careful experimental work. Considering that the points plotted were the results of five different investigations which were no doubt conducted under varying conditions this conclusion looks more convincing.

Table 4

TRANSVERSE TESTS OF ARBITRATION TEST BARS

SPECIMENS AND DATA OBTAINED WITH TEST BARS

Specimen No.	Physical Properties	
	Strength (Transverse) Pounds	Def.
1 C. I.	3400	.16
2 S. S.	4450	.18
3 S. S.	5000	.20
4 C. I.	3500	.17
5 S. S.	4350	.16
6 C. I.	3600	.17
7 S. S.	4300	.16
8 S. S.	4300	.18
9 C. I.	3600	.17
10 S. S.	4900	.17
11 C. I.	3400	.16
12 C. I.	4450	.17
13 S. S.	3250	.15
14 S. S.	4700	.18
15 C. I.	3400	.15
16 S. S. (Cyl.)	4400	.20
17 C. I.	3750	.17
18 S. S.	4700	.17
19 C. I.	3700	.18
20 C. I.	3400	.17
21 S. S.	4600	.18
22 S. S.	4650	.18
23 C. I.	3800	.20
24 S. S.	4750	.19
25 C. I.	3800	.19
26 C. I.	3700	.18
27 S. S.	4500	.17
28 C. I.	3400	.15
29 S. S.	4850	.20
30 C. I.	3600	.16
31 S. S.	4850	.20
32 S. S.	4450	.18
33 S. S.	4700	.18
34 C. I.	3750	.16
35 C. I.	3800	.18
36 S. S.	4600	.18
37		
38 S. S. (Cyl.)	4300	.17
41 S. S.	4300	.17
42 S. S.		
44 C. I.	3500	.16
45 C. I.		

Transverse Tests

Table 4 gives the results of the transverse tests of the large bars (1¼ inches by 15 inches) and Table 5 gives the results on the small bars (½ inch by 7 inches). The large bars were tested between 12 inch supports and the small bars between 6 inch sup-

ports except where noted otherwise. The special transverse testing apparatus shown in Fig. 1 was used for the small bars with an Amsler wire testing machine. The Amsler machine was equipped with an automatic deflection recording apparatus and deflection curves as shown in Fig. 6 were obtained on all transverse tests made on the small bars.

From the inspection of these curves it can be seen that stress is not directly proportional to strain and therefore the elastic limit is a very low value.

The Effect of Heat Treatment on the Transverse Properties of Cast Iron and Semi-steel

From a comparison of the data given in Table 6 the results clearly indicate that the transverse strength is reduced the longer the time of anneal above the critical. An increase in deflection also followed as would be expected. The report or sound at rupture was very different before and after annealing. The untreated bars

Table 5

TRANSVERSE TESTS ON SMALL DIAMETER BARS
UNTREATED BARS

Spec. No.	Dia. (d) Inches	Length of Span Inches	Load Pounds	Deflection Inches
11 C. I.	.497	6	440	.06
15 C. I.	.478	6	535	.07
16	.503	6	473	.07
16 S. S. (Cyl.)	.476	6	330 (Flaw)	.05
17 C. I.	.505	6	502	.07
20	.510	6	520	.085
20 C. I.	.491	6	286	.10
21 S. S.	.510	6	660	.06
22 S. S.	.499	5	550	.12
23 C. I.	.502	6	513	.08
24 S. S.	.500	6	638	.07
25 C. I.	.498	5	660	.02
26 C. I.	.461	6	423	.10
28 C. I.	.407	6	187	.04 (Flaw)
30 C. I.	.503	6	539	.07
31 S. S.	.426	6	273	.09 (Flaw)
32 S. S. (Cyl.)	.498	6	594	.07
33 S. S.	.495	6	543	.065
34 C. I.	.486	5	522	.04
35 C. I.	.488	6	484	.06
40	.497	6	484	.08
41 S. S. (Cyl.)	.500	6	598	.07
43	.500	6	539	.07
44 C. I.	.507	6	520	.06
46 S. S.	.501	6	640	.06

(Continued on next page.)

Table 5

(Continued from previous page.)

TRANSVERSE TESTS ON SMALL DIAMETER BARS
HEAT TREATED BARS

Heated to 1600° F. (870° C.) and held for 3 hours. (T-1). Cooled rapidly to black in furnace.

Spec. No.	Diameter Inches	Length of Span Inches	Load Pounds	Deflection Inches
15 C. I.	.497	6	447	.08
17 C. I.	.512	6	419	.05
19 C. I.	.429	6	397	.07
20 C. I.	.502	6	348	.08
25 C. I.	.498	6	430	.09
33 S. S.	.493	6	342	.085
40	.480	6	370	.09
42 S. S.	.500	5	634	.04
Heated to 1450° F. (790° C.) Quenched in cold water. (T-2).				
23 C. I.	.506	6	527	.06
34 C. I.	.501	5	650	.02
Heated to 1370° F. (735° C.) (T-3). Quenched in cold water.				
43	.492	6	561	.085
44 C. I.	.478	6	441	.095
Heated to 1600° F. (870° C.) and cooled in furnace. (T-4).				
21 S. S.	.410	6	127	.08
26 C. I.	.454	6	308	.09
27 S. S.	.436	6	317	.12
28 C. I.	.404	6	198	.10
30 C. I.	.492	6	430	.09
31 S. S.	.429	6	220	.09
41 S. S.	.502	6	485	.08
Quenched in oil. (T-5)				
11 C. I.	.500	6	392	.05
46 S. S.	.496	6	518	.035
Quenched in oil. (T-6).				
16 S. S.	.498	6	440	.03
36 S. S.	.493	6	584	.09

made a very loud sharp noise at rupture while the annealed ones (especially those with long anneal) broke with very much less report. This may be an indication that annealing reduces the elastic limit and also the brittleness.

Heat treatment T-1 (heating above critical and cooling rapidly) seemed to produce more uniform results than any of the others. When quenched in water from above the critical (T-2) there was a decided increase in transverse strength and a reduction in deflection. The results of the oil quench (T-6) were rather unsatisfactory and no definite conclusions can be drawn. The

Table 6

THE EFFECT OF HEAT TREATMENT ON THE TRANSVERSE PROPERTIES OF CAST IRON AND SEMI-STEEL

Spec. No.	Untreated		T-1		T-2		T-3		T-4		T-5		T-6	
	Tr.S	Def	Tr.S	Def	Tr.S	Def	Tr.S	Def	Tr.S	Def	Tr.S	Def	Tr.S	Def
11 C. I.	440	.06									392	.05		
15 C. I.	535	.07	447	.08										
16 S. S.	473	.07											440	.08
17 C. I.	502	.07	419	.05										
19 C. I.			397	.07										
20 C. I.	520	.085	348	.08										
21 S. S.	660	.06							127	.08				
23 C. I.	513	.08			527	.06								
25 C. I.	660	.02	430	.09										
26 C. I.	423	.10							308	.09				
27 S. S.									317	.09				
28 C. I.	187	.04							198	.10				
30 C. I.	539	.07							430	.09				
31 S. S.	273	.09							220	.09				
33 S. S.	543	0.65	342	.085										
34 C. I.	522	.04			650	.02								
36 S. S.													584	.09
40	484	.08	370	.09										
41 S. S.	598	.07							485	.08				
42 S. S.				.04*										
43	539	.07					561	.085						
44 C. I.	520	.06					441	.095						
46 S. S.	640	.06									518	.035		

(Abbreviations).

Tr. S.—Transverse Strength in lbs. of ½" bars on 6" centers.

Def. —Deflection in inches.

*5" centers.

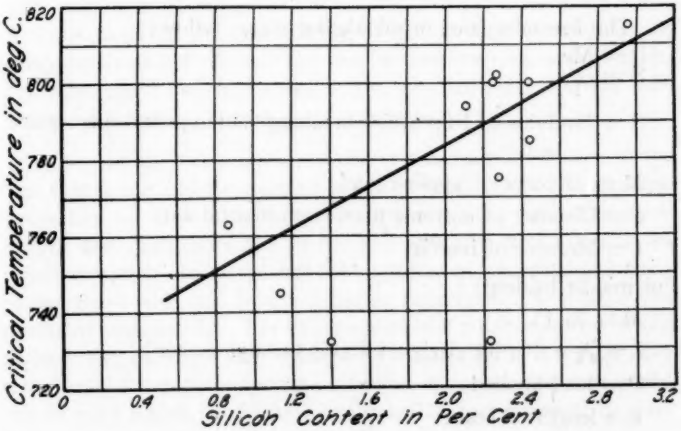

FIG. 5—SILICON CONTENT IN RELATION TO CRITICAL TEMPERATURE

effect of the transverse strength when the specimens were quenched in water from below the critical (T-3) is not conclusively apparent from these results. The increase in deflection is very marked. The oil quench from below the critical (T-5) shows, however, a decrease in both transverse strength and deflection.

These results along with the hardness records seem to affirm the records of Forsyth[4] and Harper[5] in that there is a zone just below the critical where quenching increases the amount of graphitic carbon and thus reduces its strength and hardness. Just what causes the reduction in deflection of the oil quenched specimens is not known.

Modulus of Rupture

In order to tie up in some way the results of the transverse test on bars of different dimensions, the modulus of rupture was calculated from the data of both tests and the results compared. The original arbitration bars, 1¼ inches by 15 inches were tested in the rough and the small bars tested after being machined. The machined bars (small bars) would be expected to give the more uniform results and also a higher modulus of rupture which they did in practically every case.

The formulae used in calculating are as follows:

$$S = \frac{Mc}{I}$$

S = Modulus of Rupture = breaking load in pounds per square inch

M = Moment of applied load

c = Distance of extreme fiber from neutral axis

I = Moment of inertia

For middle loading:

$M = \frac{1}{4}\ Pl$

$I = \frac{1}{64}\ \pi\ d^4$ (for circle with axis through center)

P = load applied

l = length of beam

[4] A. C. Forsyth, 1924, Met. Thesis, University of Minnesota.
[5] Vol. 30, Trans. Am. Fdry. Assoc.

$$\text{Therefore, } S = \frac{Mc}{I} = \frac{(\frac{1}{4}\,Pl) \times r}{\frac{1}{64}\pi\,(2r)^4} = .318\frac{Pl}{r^3} + \frac{2.544\,Pl}{d^3}$$

This formula holds only up to the elastic limit and therefore these results are not strictly correct because they involve data taken beyond the elastic limit.

G. B. Upton in his text book "Materials of Construction" gives the following formula:

$$T = \frac{3}{bh^2} \cdot M \left(1 + \frac{1}{\sqrt{\frac{Ec}{Et}}} \right)$$

T = Calculated tensile strength

b and h = dimensions of cross section of rectangular bar

M = Moment

Ec = Modulus of elasticity in compression

Et = Modulus of elasticity in tension

He states Ec is usually twice Et. Since the moduli of elasticity of cast iron is such a variable quantity and rather difficult to determine it is seldom given any value. For that reason the above formula involves the determining of the moduli of elasticity on every batch or test made. The results then are only approximate. For this reason the simple modulus of rupture formulae was used and is sufficient for purposes of comparison.

One of the serious objections to the transverse test is the fact that it cannot be compared with any other results, or strength properties of any other materials unless tested with the same shaped and sized cross section bar and with the same distance between supports. In discussing the strengths of materials and comparing them with cast iron, tension or compression is usually the means of comparison. For this purpose the transverse test is not entirely satisfactory. For weak, brittle materials it is a very easy test to make but there is some question if some other test could not be used which would be more valuable for comparative purposes.

The moduli of rupture for the two kinds of bars as calculated are given in Table 7.

Tensile Tests

Twelve bars were tested in tension in order to compare the results with the other physical properties. It will be noted that with the exception of specimen No. 12, all semi-steel specimens were from 25 to 50 percent stronger than the grey irons. It seems very possible that specimen No. 12 is a semi-steel and was tagged wrongly. The results are shown in Table 8. Neglecting No. 12, the average tensile strength of the semi-steel is 33,226 pounds per square inch while it is only 23,276 for the grey iron.

Table 7

EFFECT OF SIZE OF SPECIMEN ON TRANSVERSE PROPERTIES OF CAST IRON AND SEMI-STEEL

	Standard Bars		Small Bars		Modulus of Rupture	
Spec. No.	Def. Inches	Load Pounds	Def. Inches	Load Pounds	d=1.25	d=.5
11 C. I.	.16	3400	.06	440	53,185	53,815
15 C. I.	.15	3400	.07	535	53,185	74,600
16 S. S. (Cyl.)	.20	4400	.07	473	64,600	57,000
17 C. I.	.17	3750	.07	502	58,500	59,500
20 C. I.	.17	3400	.085	520	53,185	59,900
21 S. S.	.18	4600	.06	660	71,700	75,900
22 S. S.	.18	4640	.12	550	72,500	66,200
23 C. I.	.20	3800	.08	513	59,400	61,700
24 S. S.	.19	4750	.07	638	74,100	77,700
25 C. I.	.19	3800	.02	660	59,400	80,400
26 C. I.	.18	3700	.10	423	57,700	68,900
28 C. I.	.15	3400	.04	187	53,000	42,400
30 C. I.	.16	3600	.07	539	56,200	64,500
31 S. S.	.20	4850	.09	273	75,700	53,900
32 S. S. (Cyl.)	.18	4450	.07	594	69,500	72,800
33 S. S.	.18	4700	.085	543	73,400	68,300
34 C. I.	.16	3750	.04	522	53,500	69,400
35 C. I.	.18	3800	.06	484	59,300	63,600
41 S. S. (Cyl.)	.17	4300	.07	598	67,100	73,200
44 C. I.	.16	3500	.06	520	54,600	60,800

On the other hand the cast iron showed an average elongation of 3.5 percent and the semi-steel only 2 percent.

To establish a relation between tensile strength and transverse strength the graph shown in Fig. 7 was drawn.

Impact Tests

The broken specimens from the transverse test on the ½-inch diameter bars were cut to lengths of about 3 inches and tested on a Charpy impact machine set with the jaws 2 inches apart. The bars were tested without notching. The following formulae

were used to convert the readings into KgM and these values were then converted in foot pounds.

1. $\Delta h = ho - h$ — Δh=Difference between free swing of pendulum and swing when breaking specimen.
   ho=Height of free swing of pendulum.
   h=Swing of specimen after breaking specimen.
2. $h \times w = E$ — w=23.19 Mg (Wt. of pendulum)
   E=Energy absorbed in breaking specimen in Meter Kilograms.

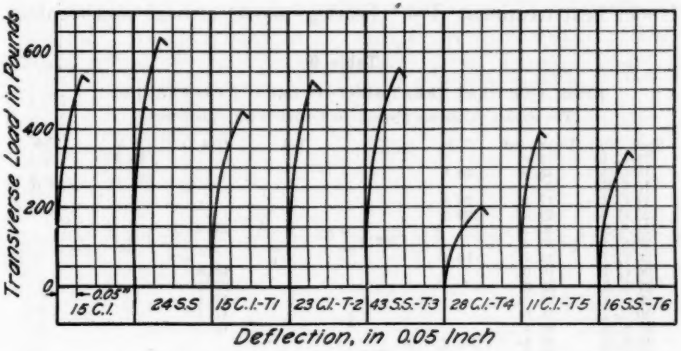

FIG. 6—TRANSVERSE DEFLATION CURVES OBTAINED BY USE OF AMSLER MACHINE

Table 8

TENSILE STRENGTH

Spec. No.	Tensile Strength (lb. per sq. in.)	Elongation		Fracture
1 C. I.	21,340	.04	4%	Granular
1 C. I.	26,200	.02	2%	"
2 S. S.	34,560	.04	4%	"
3 S. S.	33,250	.01	1%	"
5 S. S.	31,920	.01	1%	"
6 C. I.	22,640	.04	4%	"
7 S. S.	30,640	.02	2%	"
9 C. I.	20,200	.02	2%	"
12 C. I.	34,640	.05	5%	"
15 C. I.	24,920	.04	4%	"
24 S. S.	35,960	.02	2%	"
45 C. I.	24,360	.05	5%	"
	Average Values:			
Ave. C. I.	23,276		3.5%	
Ave. S. S.	33,226		2 %	

The fact that the bars used in this test were not standard and that the gauge lengthens between the jaws of the machine were also not standard makes it impossible to compare these results with standard tests. However, the results of these tests on semi-steel and on grey iron are comparable and furnish a means of comparing the impact properties of the two materials and of studying the effects of heat treatment on this property. The data are given in Table 9.

Effect of Heat Treatment on Impact Properties

Some interesting relations are shown by these results. On heat treatment T-1 (heating above critical and cooling rapidly) four out of six tests showed a decided increase in impact values. Under heat treatment T-4 (heating above critical and cooling

Table 9

EFFECT OF HEAT TREATMENT ON IMPACT PROPERTIES

(The impact values are given in foot-pounds per square inch)

Spec. No.	Untreated	T-1	T-2	T-3	T-4	T-5	T-6
11 C. I.	18.8					16.3	
15 C. I.	23.8	25.6					
16 S. S.	29.0						28.0
17 C. I.	17.2	20.4					
20 C. I.	21.0	29.1					
21 S. S.	20.5				27.0		
23 C. I.	21.6		27.3				
25 C. I.	14.7	16.4					
26 C. I.	19.0				18.8		
27 S. S.	20.9				20.3		
28 C. I.	27.3				17.1		
30 C. I.	18.0				17.5		
31 S. S.	20.4				15.2		
33 S. S.	26.4	25.0					
34 C. I.	20.1		29.6				
36 S. S.	25.3						36.7
40	23.8	15.9					
41 S. S.	28.6				27.1		
43	25.8		33.0				
44 C. I.	24.4		22.0				
46 S. S.	25.6					30.0	

slowly in furnace) only one out of seven tests showed an increase while most of them showed a very decided decrease in impact values.

When quenched from above the critical in both water and oil (T-2 and T-6 respectively) three out of four tests showed a decided increase in impact values. When quenching from below the critical (T-3 and T-5) the results are rather erratic, one each of the water and oil quench showing a marked increase and the other two showing a slight decrease.

It is quite evident that the impact values are very sensitive to the effects of heat treatment and it might be advisable to study their relation further, with reference to commercial use.

Hardness of Cast Iron and Semi-steel as Cast and as Heat Treated

Both the Brinell and Scleroscope hardnesses were recorded before and after heat treatment. All tests were made on a clean rough polished end section.

The Scleroscope hardness values are given in Table 10 and the Brinell hardness in Table 11.

Table 10

THE EFFECT OF HEAT TREATMENT ON SCLEROSCOPE HARDNESS

Spec. No.	11 C. I.	12 C. I.	15 C. I.	16 S. S. (Cyl.)	17 C. I.	19 C. I.	20 C. I.
Untreated:	38	39	35	39	39	34	40
T-1			33.3		33.6	35.6	34.0
T-2							
T-3							
T-4							
T-5	37.1						
T-6				43.3			
T-7		69					
T-8	60						
T-9							
T-10							

Spec. No.	21 S. S.	23 C. I.	24 S. S.	25 C. I.	26 C. I.	27 S. S.	28 C. I.	30 C. I.
Untreated:	39	35	40	40	39	41	40	39
T-1				30.7				
T-2		55.2						
T-3								
T-4	31.4				31.3	32.9	30.3	30.9
T-5								
T-6			85					
T-7								
T-8								
T-9		37						
T-10			36.5					

Spec. No.	31S.S.	32S.S.	33S.S.	34C.I.	36S.S.	40	41S.S. (Cyl.)	42S.S.	43	44C.I.	45C.I.	46S.S.
Untreated:	38	39	39	35	40	36	40	38	39	36	41	38
T-1			32.4		34.0		32.9					
T-2				61.3								
T-3									42.5	39.2		
T-4	34.7						30.8					
T-5												36.8
T-6		61		55	43				62			
T-7	73											
T-8						80						
T-9												40
T-10				37								

From these results it is evident that hardness is very materially affected by heat treatment. The higher temperature and the longer heat treatment, without quenching, results in the softer material. The specimens heated to 870 degrees Cent. (T-1) and

cooled rapidly were greatly softened but not nearly so much as those heated to 870 degrees Cent. (T-4) and allowed to cool slowly in furnace. The drawing of the quenched specimens as in T-9 and T-10 produced softness again, reducing the Scleroscope reading from 85 to 36.5 and 55 to 37, respectively.

One important thing to note is that the annealed specimens (T-1 and T-4) showed a tendency towards uniform hardness which is a very desirable quality.

For purposes of comparison a Brinell hardness was taken on a piece of armco iron which is nearly pure ferrite and was found to be 82. Comparing this with the records of specimens heated to 870 degrees Cent. (T-4) and allowed to cool slowly in the furnace it is seen that it approached very closely the softness of pure ferrite which means that practically all of the cementite (both

Table 11

THE EFFECT OF HEAT TREATMENT ON BRINELL HARDNESS

Spec. No.	Untreated	T-1	T-2	T-3	T-4	T-5	T-6
11 C. I.	181					143	
15 C. I.	201	114					
16 S. S. (Cyl.)	196						194
17 C. I.	183	114					
19 C. I.	170	132					
20 C. I.	179	115					
21 S. S.	212				101		
23 C. I.	207		238				
24 S. S.	207						321
25 C. I.	196	107					
26 C. I.	202				90		
27 S. S.	217				99		
28 C. I.	183				98		
30 C. I.	187				114		
31 S. S.	196				88		
33 S. S.	202	114					
34 C. I.	187		278				
36 S. S.	196						121
40	192	118					
41 S. S. (Cyl.)	202				107		
42 S. S.	207	114					
43	207			152			
44 C. I.	179			131			
46 S. S.	210					147	

The average values and the maximum variations were as follows:

	Average of Results		Maximum Variation	
	Brinell	Scleroscope	Brinell	Scleroscope
Untreated	195.3	38	47	6
T-1	116	33.3	25	4.9
T-2	258	58.3	40	6.1
T-3	141.5	40.8	21	3.3
T-4	99.4	31.8	24	4.4
T-5	145	37	2	.3
T-6	213	58	200	42
T-7		71		4
T-8		70		20
T-9		38.5		3
T-10		36.75		.5

primary and pearlitic) has been decomposed. This is corroborated in the record of chemical analysis and micrographs.

Specimens quenched from above the critical in both oil and water showed a very decided hardening effect. The results were rather erratic, however, indicating that when quenched from above the critical that the material was quite sensitive to any slight change in quenching conditions.

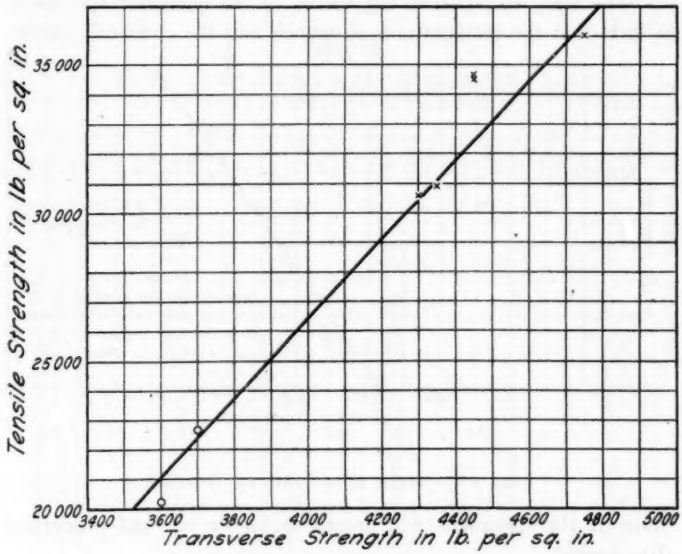

FIG. 7—RELATION OF TRANSVERSE AND TENSILE STRENGTH
O=GREY CAST IRON; X=SEMI-STEEL

Relation of Hardness to Strength Properties

While the Brinell and Scleroscope hardnesses in general indicated the same tendencies the Brinell seemed to be more definite in those indications. Ordinarily in metals or alloys the Brinell value is usually considered proportional to the ultimate strength and the Scleroscope proportional to the elastic limit. See graph of Fig. 8. With the exception of specimen No. 12, the points indicate that Brinell hardness is roughly proportional to ultimate

tensile strength. The "x" marks indicate the Scleroscope hardness and they seem to have no particular relation to ultimate tensile strength. The elastic limit of cast iron is known to vary from 0 up to near the ultimate strength, depending upon its chemical composition and the condition of the elements in the specimen. It is not possible to say whether the Scleroscope readings are a function of the elastic limit or not.

The wide variation in the values of the quenched specimens indicate that the temperature of quench and the chemical compo-

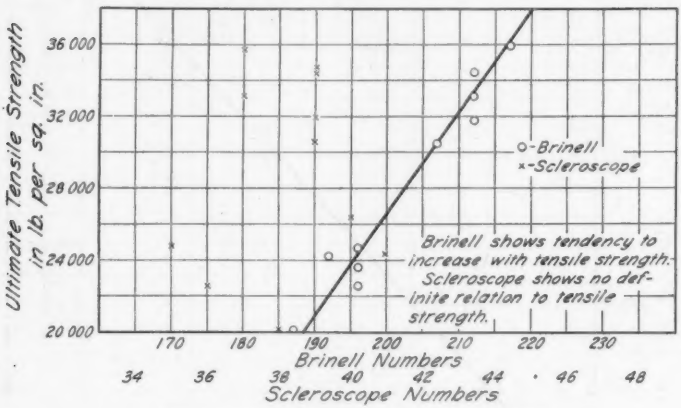

FIG. 8—TENSILE STRENGTH VS. HARDNESS

sition of the specimens will greatly influence its final properties after quench.

The oil quenched specimens show quite a marked tendency to soften when quenched from below the critical and to harden when quenched from above the critical. The results of the water quench show a similar relation except that they are more pronounced. It was impossible to drill those specimens quenched from above the critical in water, while those quenched from below the critical drilled very easily.

Other investigators have found these same results. Harper[6] and Forsyth[7] found that when the specimens were quenched

[6]Vol. 30, Trans. Am. Fdry. Assoc.
[7]Met. Thesis. 1924. University of Minnesota.

from temperatures between 700 and 800 degrees Cent. there was a softening effect.

Effect of Heat Treatment on Dimensions of Grey Cast Iron and Semi-steel

The results of this series of tests are given in Table 12. The experimental methods are given in connection with that table.

Table 12

EFFECT OF HEAT TREATMENT ON DIMENSIONS OF GREY CAST IRON AND SEMI-STEEL

Specimens were marked with center punches approximately 5" apart and .052" holes drilled. Four gauge lengths at right angles to each other were marked on each specimen and the distances measured with a strain gauge before and after heat treatment. The average of the readings for each specimen is as follows:

Spec. No.	Length before Treatment	Length after Treatment	Change in Length	% Change in Length	Heat Treatment
15 C. I.	5.063	5.130	.067	1.32	T-1
17 C. I.	5.078	5.139	.061	1.20	"
19 C. I.	5.075	5.123	.048	4.6	"
20 C. I.	5.083	5.294	.211	1.4	"
25 C. I.	5.104	5.176	.072	.95	"
33 S. S.	5.079	5.184	.105	2.07	"
40	5.093	5.165	.072	1.42	"
42 S. S.	5.091	5.177	.086	1.69	"
23 C. I.	5.075	5.070	.005	0.0	T-2
34 C. I.	5.078	5.086	.008	0.0	"
43	5.054	.....	Shrank	....	T-3
44 C. I.	5.092	5.058	—.034	—.67	"
21 S. S.	5.086	5.167	.081	1.59	T-4
26 C. I.	5.077	5.181	.104	2.06	"
27 S. S.	5.078	5.167	.089	1.75	"
28 C. I.	5.113	5.232	.119	2.33	"
30 C. I.	5.072	5.139	.067	1.17	"
31 S. S.	5.087	5.114	.037	.73	"
41 S. S.	5.084	5.117	.033	.65	"
11 C. I.	5.076	5.040	—.036	—.71	T-5
46 S. S.	5.074	5.053	—.021	—.41	"
16 S. S.	5.099	5.106	.007	0.0	T-6
36 S. S.	5.035	5.137	.102	2.03	"

NOTE: All changes are increases except as indicated.

Heat treatments, T-3 and T-5, water and oil, respectively, are quenched from below the critical in oil and water respectively from above critical show practically no change.

The permanent growth is distinctly shown in all specimens not quenched. In all quenched specimens there was a tendency towards a shrinkage instead of a growth. It is interesting to note that those indicating definitely a shrinkage were those that were quenched from 735 degrees Cent. which is just below the critical

for this material as determined by thermal analysis. This would seem to indicate that there is a shrinkage in volume of grey cast iron and semi-steel at a temperature somewhat below the critical. This may possibly be due to spheroidizing and decomposition of cementite.

It has been contended by most investigators that the phenomenon of growth in cast iron is due to graphitic carbon. There has been some controversy in regard to the exact condition of the graphite. Recent experimenters have conclusively shown graphite in cast iron to be crystaline[8]. The different forms of carbon (graphite, diamond, charcoal, etc.) indicate it has a number of stable forms which vary considerably in density. Experiments on heating graphite and cooling rapidly by quenching have greatly raised the density[8]. This is the same as reducing the volume for a given mass. Under the above quenching conditions this seems to be borne out. The condensing of the graphite under quenching has the effect of reducing the dimensional values.

The fact that this did not occur on specimens heated above the critical and quenched is probably due to the absence of the graphite which has gone into solution in the ferrite as austenite.

The average growths under the various heat treatments were as follows:

Heat Treatment	Growth in Percent
T-1	+1.92
T-2	0
T-3	— .67
T-4	1.47
T-5	— .56
T-6	0

The greatest average dimensional change (increase) occurred when the test bars were heated above the critical and cooled rapidly without quenching. Under the long soaking in the furnace as in T-4 there seemed to be less permanent growth.

All the above effects suggest that the carbon may be going through an allopropic change with a corresponding change in space

[8]E. Adamson. The Foundry. September, 1923.

lattice and density on heating which is only partially reversible on slow cooling. This would be a reasonable explanation if there were a specific limit of this growth when all of the graphitic carbon had undergone this change. The experiments of Outerbridge[9] and others, however, seem to show no such growth limit under repeated heating and cooling. The absorption of gases from the furnace atmosphere and the formation of gases by oxidation at the high temperatures have been proposed by some to account for the growth of cast iron and this should receive at least some consideration in connection with this investigation. It is well known that grey iron is a quite pervious metal and the circulation of gas is no doubt an influencing element on the growth phenomena. In order to carry out this part of the work it would probably be necessary to vary the composition of the furnace atmosphere and to make analyses of the gases contained in the specimens before and after heating (heat treating). Lack of time and apparatus have prevented including such tests in this work.

Plotting the dimensional changes against silicon and total carbon content shows some rather unexpected tendencies. The data are shown in Table 13 and the graphs in Fig. 9. Upon heating above the critical, holding 3 hours, cooling to black in 15 minutes and then cooling rapidly in air (T-1) the tendency is quite distinct that the dimensional changes increase with decreased quantities of silicon and total carbon. This is quite the reverse of what would be expected if the phenomena of growth were entirely due to the amount of graphite present, since graphitic carbon is definitely known to be high in the high silicon irons, which is confirmed by the chemical analysis of this investigation. When cooling in furnace slowly from above the critical as in T-4, the results seem to be reversed and growth increases with increase in silicon and total carbon content.

More investigations must be done before any definite conclusions can be drawn.

Microscopic Studies

The study of the microstructures in conjunction with the physical and chemical properties is a great aid to the deductions of

[9]Journal of Iron and Steel Inst. Vol. 83, No. 1, p. 643.

causes for the properties and the change in properties under heat treatment. With this object in view a large number of specimens were examined both before and after heat treatment. They were examined first as polished, showing relief and then as etched with picric acid or sodium picrate. They were examined at low and high powers and the best representative structures were recorded as shown in the accompanying micrographs.

All specimens were polished with emery paper 1, 0, 00, 000, and then on the rouge wheel. In all cases the specimens were

Table 13

RELATION OF SILICON AND TOTAL CARBON TO DIMENSIONSAL CHANGES

Spec. No.	% Change in Length	Si. %	T. C. %	Heat Treatment
15 C. I.	1.32	2.11	3.32	T-1
17 C. I.	1.20	2.44	3.41	"
19 C. I.	.95	2.44	3.42	"
20 C. I.	4.60	2.25	3.49	"
25 C. I.	1.40	2.16	3.23	"
33 S. S.	2.07	1.92	3.22	"
23 C. I.	0	2.09	3.38	T-2
34 C. I.	0	1.79	3.44	"
43				T-3
44 C. I.	∔.67	2.58	3.46	"
21 S. S.	1.59	1.95	3.19	T-4
26 C. I.	2.05	2.09	3.23	"
27 S. S.	.175	1.92	5.05	"
28 C. I.	2.33	2.11	5.15	"
30 C. I.	1.17	2.16	3.23	"
31 S. S.	.73	1.87	3.23	"
41 S. S.	.65	1.97	5.15	"
11 C. I.	∔.71	2.18	3.33	T-5
46 C. I.	∔.41			"
16 S. S.	0	1.40	5.18	T-6
36 S. S.	0	1.82	3.22	"

∔These specimens showed shrinkage instead of growth.

etched and rebuffed before photographing. This seemed to give a clear and flatter field.

Micrographs 1, 2, and 3 (Fig. 10) show a representative appearance of polished sections from cast grey iron and semi-steel cast from the same heat (the same day's run), at 50 diameters. Micrograph No. 7 (Fig. 12) shows characteristic appearance at 100 diameters. Micrograph No. 1 is of cast grey iron, sample No. 30; No. 2 is of semi-steel, sample No. 31; while No. 3 is sample No. 32, a special semi-steel for cylinders; and No. 7 is of cast iron, specimen No. 25. The amount and distribution of the

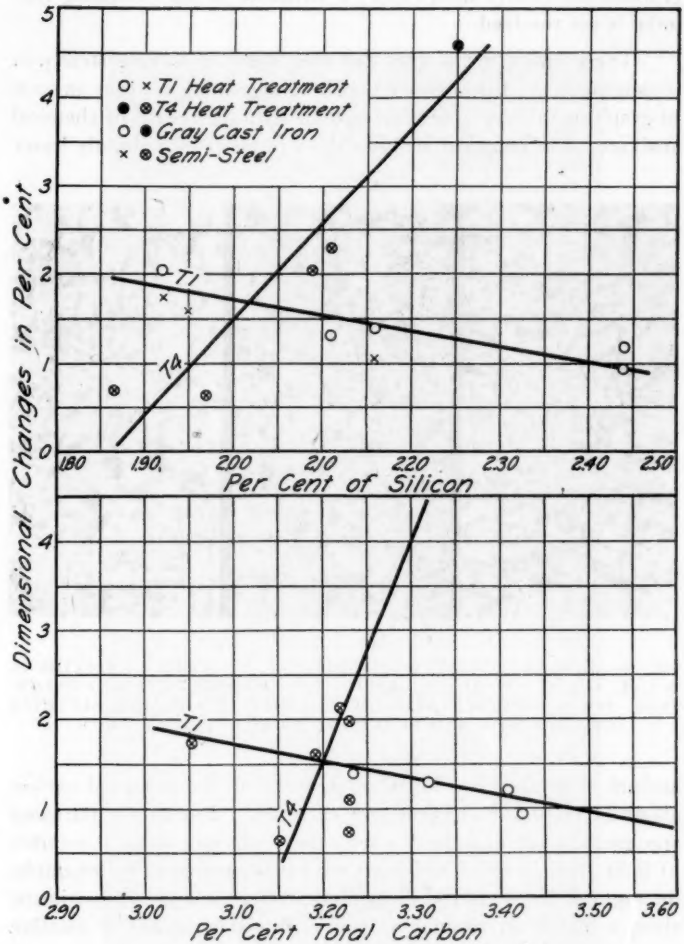

FIG. 9—RELATION OF DIMENSIONAL CHANGES TO SILICON AND TOTAL CARBON UNDER HEAT TREATMENTS T1 AND T4

graphite are clearly shown but the structure of the remaining material is not resolved.

The graphite in the grey cast iron seems to be consistently in somewhat larger flakes closer together, suggesting a larger amount of graphitic carbon. This corresponds with the results of chemical analyses. The chemical analyses show in all cases a slightly lesser

FIG. 10—MICROGRAPHS (LEFT TO RIGHT) NOS. 1, 2 AND 3, OF SPECIMENS 30 C. I., 31 S. S. AND 32 S. S.—RELIEF POLISHED MAGNIFIED 50 DIAMETERS. SHOW REPRESENTATIVE APPEARANCE OF POLISHED SECTIONS OF CAST IRON AND SEMI-STEEL FROM SAME DAY'S RUN

amount of total carbon in the semi-steel with the combined carbon about the same as that in the grey cast iron. Most of the untreated specimens when examined after relief polishing show a number of light areas in relief which are evidently cementite, for example, micrograph No. 7 at 100 diameters. After etching, all specimens show a matrix of laminar pearlite with some patches of massive cementite and the phosphide, steadite. The grey cast iron in general, shows a greater amount of massive cementite than the semi-steels as is illustrated by micrographs No. 4 compared with Nos. 5 and 6 (Fig. 11) which were specimens Nos. 30, 31, and 32, respectively, cast from the same day's run. The cast iron struc-

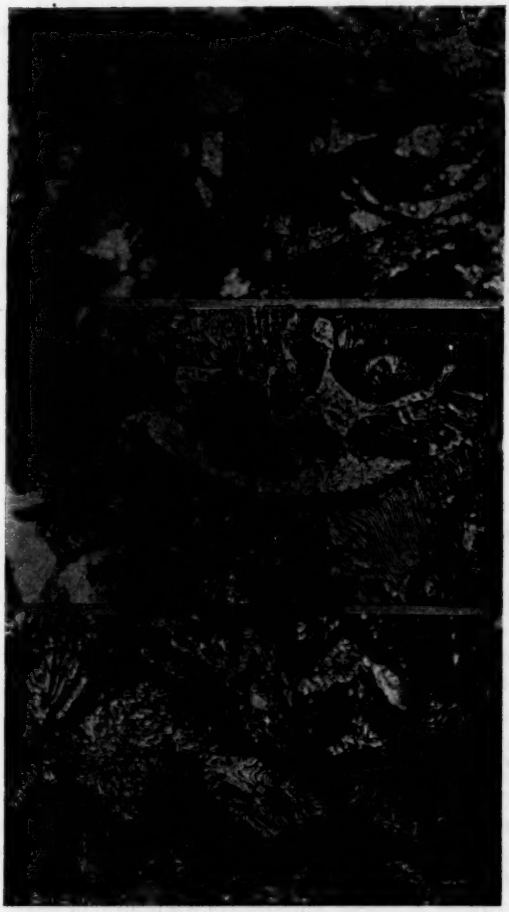

FIG. 11—MICROGRAPHS NO. 4 UPPER, NO. 5 CENTER, NO. 6 LOWER—SAME SPECIMENS AS NO. 10 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

ture seemed also to be more irregular with larger graphitic flakes and with a background matrix of a rather peculiar fine grained form of pearlite interspersed with massive cementite. This is shown in micrographs Nos. 4 and 8. In the case of semi-steel for example No. 31, micrograph No. 5, the graphite flakes are somewhat thinner, more distinct and usually occur next to massive cementite. In specimen No. 32 which was a low silicon semi-steel, the matrix was a very characteristic pearlite with practically no massive cementite.

It is usually supposed that semi-steel is finer grained than grey cast iron but under the microscope because of the pearlitic structure, the grain size was not evident. The microscopic examination shows that semi-steels are more nearly completely pearlitic than the grey irons. The pearlitic structure is known to be the strongest form of cast grey iron and therefore this answers in part why semi-steel is always stronger than grey iron.

Effect of Heat Treatment on the Micro-structure of Cast Iron and Semi-steel

Heat Treatment T-1: (Heated to 870 degrees Cent., held for three hours cooled to black in furnace in 15 minutes and then air cooled).

This heat treatment had a very decided effect on the micro-structures. Micrographs Nos. 7 and 9 (Figs. 12 and 13) show the appearance at 100 diameters, of an untreated specimen and one heated according to the heat treatment T-1, relief polished. The heat treated specimen has clearly more and larger graphitic flakes. By comparing micrographs Nos. 8 and 10 (Figs. 12 and 13) etched at 500 diameters, the heat treated specimen shows a matrix with the appearance of ferrite with a small amount of cementite present; no pearlite remained. To determine if this matrix background was pure ferrite several specimens were etched for 4 hours in hot sodium picrate. Under this treatment ferrite remains unetched and appears white in relief under microscope as shown in micrograph No. 15 (Fig. 15). This treatment did not show these areas to be pure ferrite. Time prevented further tests to determine definitely what these areas are. It is possible that they are a solid solution of some kind, very likely with

FIG. 12—MICROGRAPHS NOS. 7 AND 8, SPECIMEN NO. 25 C. I.—MICROGRAPH NO. 7 ON LEFT MAGNIFIED 100 DIAMETERS, RELIEF POLISHED—MICROGRAPH NO. 8 ON RIGHT MAGNIFIED 500 DIAMETERS, ETCHED WITH PICRIC ACID

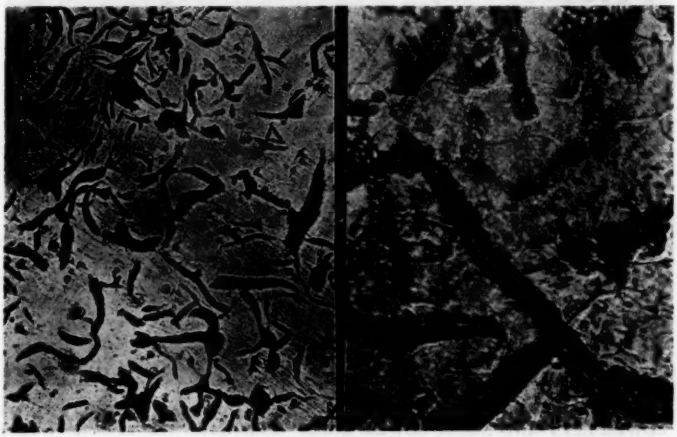

FIG. 13—MICROGRAPH NO. 9 LEFT, NO. 10 RIGHT, SAME SPECIMEN AS FIG. 12—GIVEN HEAT TREATMENT T-1—HEATED TO 870 DEGREES CENT. AND COOLED RAPIDLY—MICROGRAPH ON THE LEFT MAGNIFIED 100 DIAMETERS RELIEF POLISHED—MICROGRAPH ON THE RIGHT MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

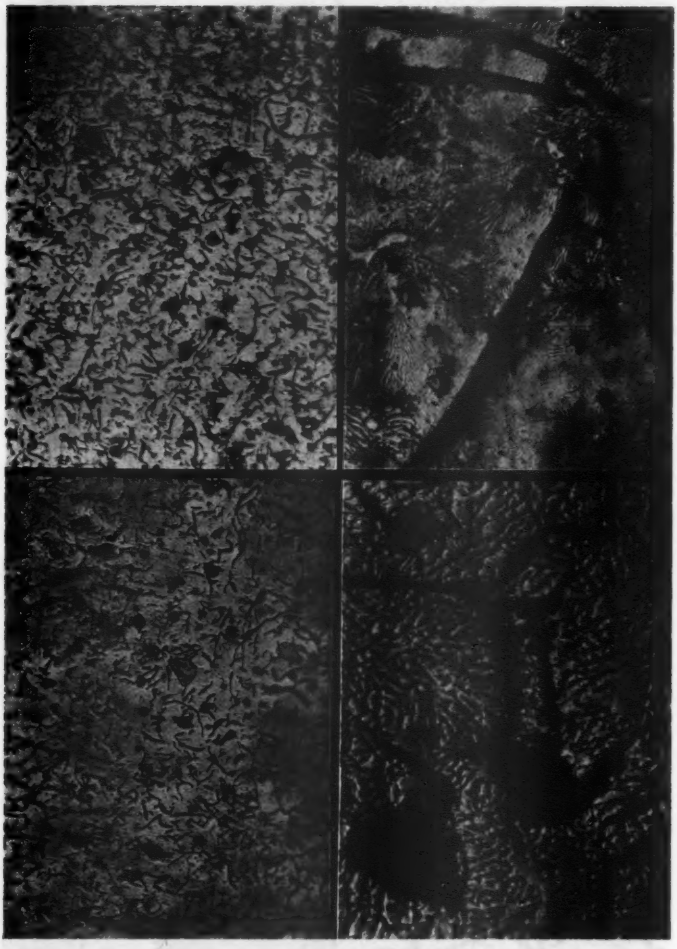

FIG. 14—MICROGRAPH NO. 11 UPPER LEFT, NO. 13 UPPER RIGHT, NO. 13 LOWER LEFT AND NO. 14 LOWER RIGHT—SPECIMEN NO. 24 S. S.—NO. 11 MAGNIFIED 50 DIAMETERS RELIEF POLISHED—NO. 13 MAGNIFIED 500 DIAMETERS ETCHED WITH PICRIC ACID—NO. 13 HEATED TO 790 DEGREES CENT. AND QUENCHED IN WATER, MAGNIFIED 50 DIAMETERS AND RELIEF POLISHED—NO. 14 SAME HEAT TREATMENT AS NO. 13 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

silicon which occurs in considerable quantities in all cast grey irons and semi-steels.

Heat Treatment T-2: (Heated to 790 degrees Cent. and quenched in water).

Micrographs Nos. 11 and 13 (Fig. 14) show the appearance in relief of specimen No. 24 S. S. before and after heat treatment T-2 at 50 diameters. The heat treated specimen seemed to show a lesser number of carbon flakes, spread out a little more and pos-

FIG. 15—MICROGRAPH NO. 15, SPECIMEN NO. 24 S. S. GIVEN HEAT TREATMENT T-2, MAGNIFIED 1000 DIAMETERS, ETCHED 4 HOURS IN HOT SODIUM PICRATE

sibly somewhat larger in average size. Micrographs Nos. 12 and 14 (Fig. 14) show the same specimens etched with picric acid at 500 diameters. Micrograph No. 14 at 500 diameters, an etched section of No. 24 S. S., shows a martensitic structure and some of the graphite in the temper carbon state. This suggests a rather hard, tough material. This is checked by the physical tests which showed a decided strengthening under this treatment. It showed a Scleroscope hardness of 65 to 70.

After etching deeply some large light areas with distinct grain boundaries appeared. These looked like pure ferrite. The focus of the microscope was changed to show which micro-con-

stituents were in relief and the order in which they came into focus was noted. They occurred in the following order: first, graphite; then martensite; and lastly, the light areas which resembled ferrite. To get further information regarding this light area, the specimen was etched in hot sodium picrate for four hours. It was then inspected at high magnification with the aid of oil

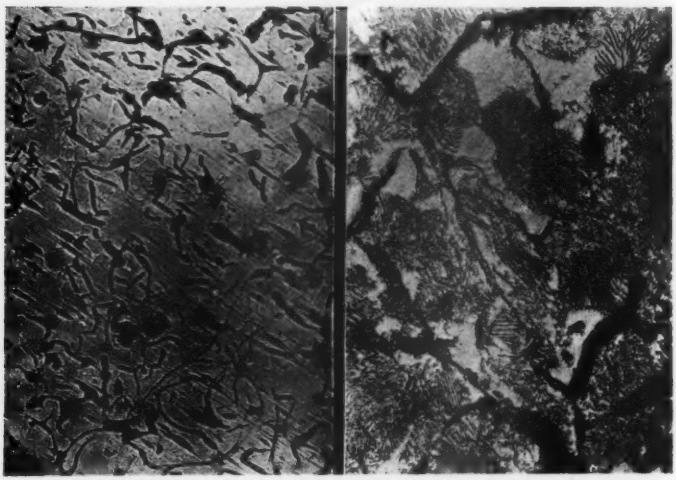

FIG. 16—MICROGRAPH NO. 16 LEFT, NO. 17 RIGHT, SPECIMEN NO. 11 C. I.—GIVEN HEAT TREATMENT T-3 (HEATED TO 735 DEGREES CENT. AND QUENCHED IN WATER)—NO. 16 MAGNIFIED 100 DIAMETERS, RELIEF POLISHED—NO. 17 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

immersion. Micrograph No. 15 shows the results. This shows a small amount of ferrite almost completely enveloping the graphite flakes. Some of the areas which appeared to be ferrite on the picric acid etch are still visible but are not ferrite as indicated by the sodum picrate test. One might expect these areas to be austenite but characteristic austenite stands out in relief against martensite in a picric acid etch and this did not. Since there is considerable silicon in cast irons this constituent may be a solid solution of Si and Fe. Further tests are necessary, however, to definitely establish its identity.

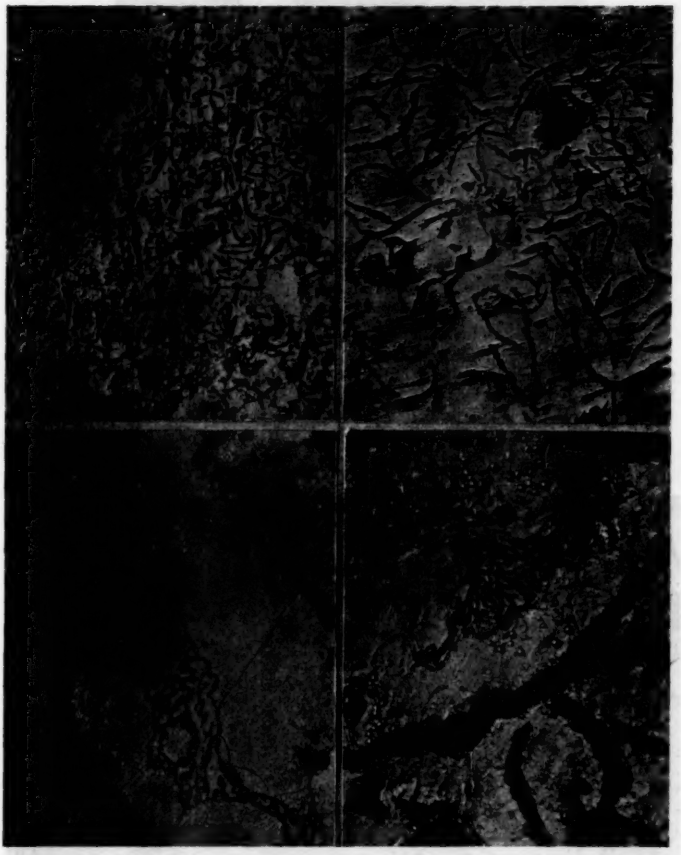

FIG. 17—MICROGRAPH NO. 18 UPPER LEFT, NO. 19 UPPER RIGHT, NO. 20 LOWER LEFT, NO. 21 LOWER RIGHT—NOS. 18 AND 20 SPECIMEN 31 S. S. HEAT TREATED (T-4) TO 870 DEGREES CENT. AND COOLED SLOWLY IN FURNACE—NO. 18 MAGNIFIED 60 DIAMETERS, RELIEF POLISHED—NO. 20 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID—NOS. 19 AND 21, SPECIMEN 25 C. I. GIVEN HEAT TREATMENT (T-4) SLOWLY HEATED TO 870 DEGREES CENT. AND COOLED SLOWLY IN FURNACE—NO. 19 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 21 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

FIG. 18—MICROGRAPH NO. 22, SPECIMEN NO. 30 C. I., GIVEN HEAT TREATMENT (T-4), HEATED TO 870 DEGREES CENT. AND COOLED SLOWLY IN FURNACE—MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

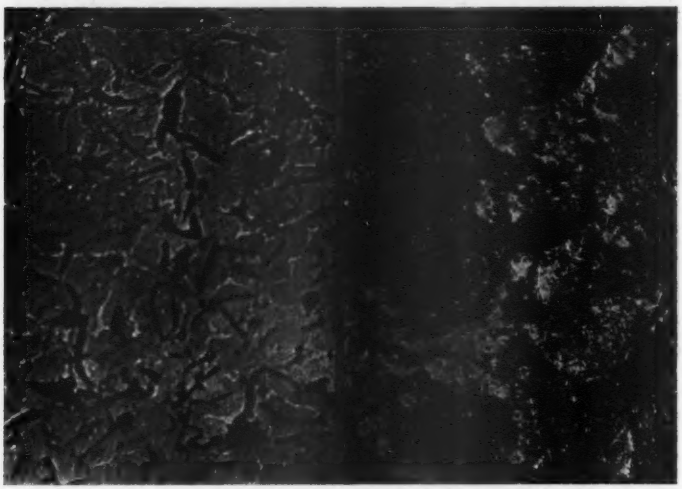

FIG. 19—MICROGRAPH NO. 23 LEFT, NO. 24 RIGHT, SPECIMEN NO. 11 C. I. GIVEN HEAT TREATMENT (T-5) HEATED TO 785 DEGREES CENT. AND QUENCHED IN OIL—NO. 23 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 24 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

Heat Treatment T-3: (Heated to just below the critical, 735 degrees Cent. and quenched in water).

The effect of this heat treatment on the microstructure is shown by comparing micrograph No. 7 with No. 16, the untreated and the quenched specimens respectively. There seems to be more graphitic carbon in the quenched specimen. This checks with the record of tests which shows a softening and a decrease in strength when quenched from just below the critical. This corroborates the results of Forsyth and of Harper previously quoted. Micrograph No. 17 (Fig. 16) is the quenched specimen etched in picric acid and shows a matrix of pearlite similar to that of the ordinary untreated cast grey iron.

Heat Treatment T-4: (Heated to 870 degrees Cent. and cooled in furnace slowly).

Comparing micrographs No. 2 with No. 18 and No. 19 (Fig. 17) with No. 7 shows the heat treated specimens to contain considerably more graphitic carbon. There is also quite a decided tendency towards the formation of temper carbon as shown by the rounded masses in micrographs Nos. 18 and 19. When etched with picric acid we find that the matrix of pearlite has disappeared and it now has the appearance of ferrite with only a very small amount of massive cementite and the steadite remaining as shown in micrographs Nos. 20 and 21 and 22 (Figs. 17 and 18). Comparing these with micrograph No. 10, the annealed specimen with rapid cooling, there does not seem to be any appreciable difference in appearance. There is, however, a slight tendency towards a smaller grain sized background matrix under treatment T-1. The larger grain size evidenced in T-4 treatment must be attributed to the longer time above critical due to slow cooling.

Heat Treatment T-5: (Heated to 735 degrees Cent. and quenched in oil).

Specimens subjected to this treatment as shown in micrographs Nos. 23 and 24 (Fig. 19) show a decided increase in graphitic carbon and the retention of the pearlitic background. This is even more marked than when quenched in water as shown in micrographs Nos. 16 and 17. The records of physical test

again corroborate with the microstructures in showing a decided softening and reduction in strength when quenched in oil from below the critical temperature.

Heat Treatment T-6: (Heated to 790 degrees Cent. and quenched in oil).

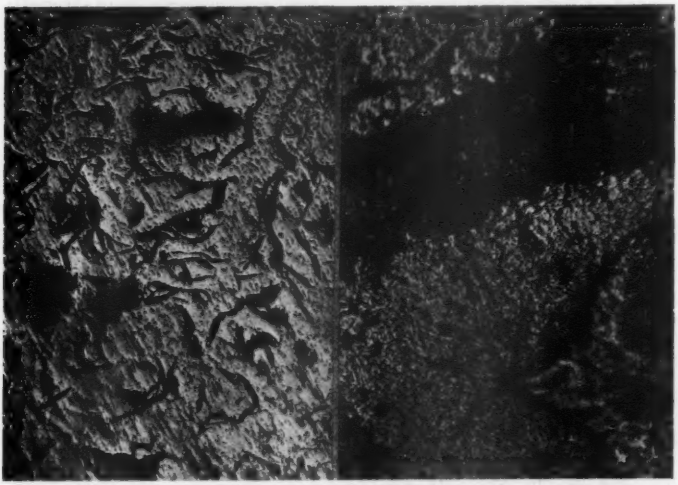

FIG. 20—MICROGRAPH NO. 25 LEFT, NO. 26 RIGHT, SPECIMEN NO. 24 S. S., GIVEN HEAT TREATMENT (T-6) HEATED TO 790 DEGREES CENT. AND QUENCHED IN OIL—NO. 25 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 26 MAGNIFIED 1000 DIAMETERS AND ETCHED WITH PICRIC ACID

These specimens show evidence of the presence of some temper carbon on relief polishing as shown in micrograph No. 25 (Fig. 20). When etched in picric acid and viewed with oil immersion objective at 1000 diameters there appeared graphite flakes with some massive cementite steadite, and a background of very fine grained martensite. This is shown in micrograph No. 26 and checks the record for hardness and physical tests which showed an increase in both hardness and strength, but to a lesser degree than for the water quenched specimens.

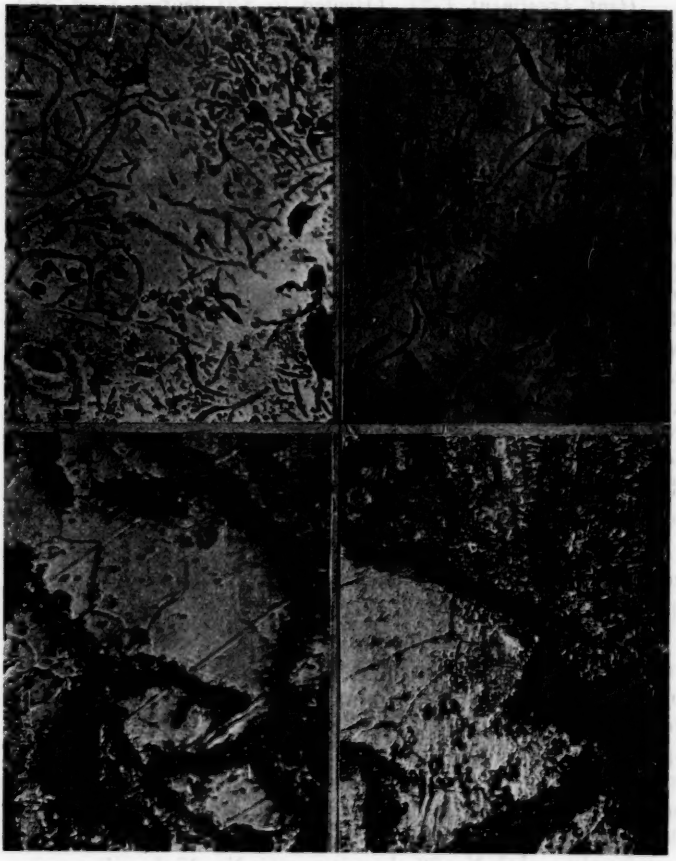

FIG. 21—MICROGRAPH NO. 27 UPPER LEFT, NO. 28 UPPER RIGHT, NO. 29 LOWER LEFT AND NO. 30 LOWER RIGHT—NOS. 27 AND 29 SPECIMEN NO. 31 S. S. GIVEN HEAT TREATMENT (T-7) ANNEALED, HEATED TO 910 DEGREES CENT. AND WATER QUENCHED—NO. 27 MAGNIFIED 100 DIAMETERS RELIEF POLISHED—NO. 29 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID—NOS. 28 AND 30, SPECIMEN 11 C. I. GIVEN HEAT TREATMENT (T-8) ANNEALED, HEATED TO 910 DEGREES CENT. AND OIL QUENCHED—NO. 28 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 30 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

Heat Treatment T-7: (Heated to 870 degrees Cent. and cooled slowly in furnace, reheated to 910 degrees Cent. and quenched in water).

For this treatment specimens already subjected to heat treatment T-4 were heated to 910 degrees Cent. and water quenched. This was done to check the statement of Schaap that after annealing, quenching from above the critical did not produce white iron. Under this treatment the Scleroscope hardness was raised from original hardness of about 38 and annealed hardness of about 35 to a hardness of 71 average. The structure is not a typical white iron, however, and no typical martensitic structure appeared as in the specimens quenched from above the critical before annealing. Micrograph No. 27 (Fig. 21) shows specimen No. 31 S. S. under relief polishing after being subjected to this treatment. There is a distinct evidence of the graphite being spheroidized. Micrograph No. 29 (Fig. 2) shows the same specimen etched in picric acid at 500 diameters. This shows a fuzzy appearance to all the graphite flakes with the background showing up as a solid solution resembling ferrite.

Heat Treatment T-8: (Heated to 870 degrees Cent. and cooled slowly in furnace, reheated to 910 degrees Cent. and quenched in oil).

For this treatment specimens previously subjected to heat treatment T-4 were reheated to 910 degrees Cent. and quenched in oil. The effect of this treatment was essentially the same as for heat treatment T-7. Micrograph No. 28 (Fig. 21) shows specimen No. 11 C. I. under relief polishing at 100 diameters and micrograph No. 30 shows the same specimen etched with picric acid at 500 diameters. The spheroidizing of the graphite is evidenced by the small patches scattered throughout the specimen as seen in micrograph No. 28. In micrograph No. 30 there is a structure resembling somewhat martensite but it is not typical. The hardness on these specimens also showed a very great increase (35 to 60 Scleroscope).

Heat Treatment T-9: (Heated to 790 degrees Cent., quenched in water and drawn at 700 degrees Cent.).

For this treatment specimens previously subjected to heat treatment T-2 were drawn at 700 degrees Cent. Micrographs

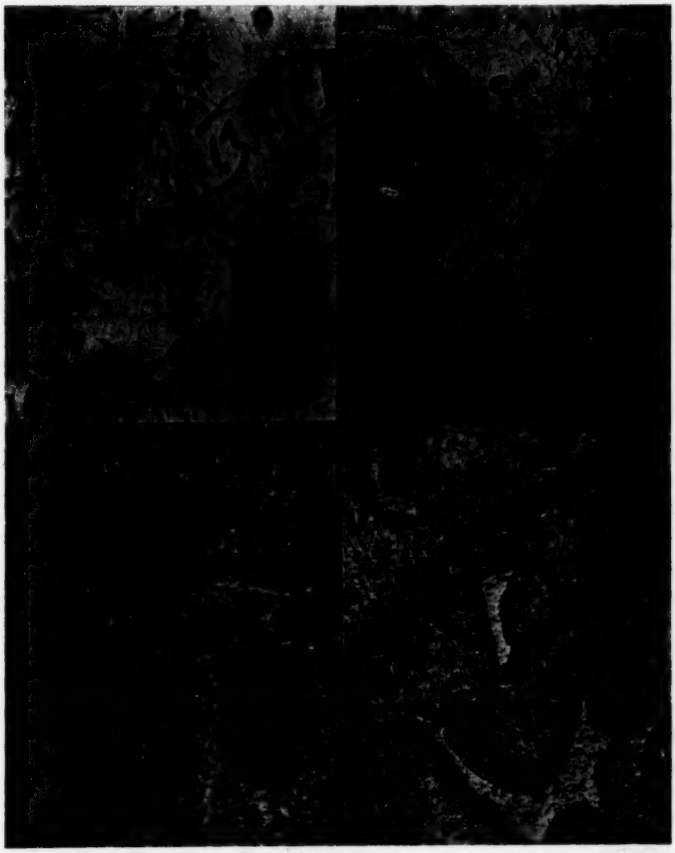

FIG. 22—MICROGRAPHS NO. 31 UPPER LEFT, NO. 32 UPPER RIGHT, NO. 33 LOWER LEFT, NO. 34 LOWER RIGHT—NOS. 31 AND 33, SPECIMEN 23 C. I. GIVEN HEAT TREATMENT (T-9) HEATED TO 790 DEGREES CENT. QUENCHED IN WATER AND DRAWN AT 700 DEGREES CENT.—NO. 31 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 33 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID—NOS. 32 AND 34, SPECIMEN NO. 24 S. S. GIVEN HEAT TREATMENT (T-10) HEATED TO 790 DEGREES CENT., QUENCHED IN OIL AND DRAWN AT 700 DEGREES CENT.—NO. 36 MAGNIFIED 100 DIAMETERS AND RELIEF POLISHED—NO. 34 MAGNIFIED 500 DIAMETERS AND ETCHED WITH PICRIC ACID

Table 14

THE EFFECT OF HEAT TREATMENT ON THE PROPERTIES OF GREY CAST IRON AND SEMI-STEEL

Heat Treatment: T-1 (Heated to 870° C. 1600° F.) and cooled rapidly.

Spec. No.	15 C. I.		17 C. I.		20 C. I.		25 C. I.		33 S. S.		40	
Chem. Anal.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.
T. C.			3.41	3.36	3.49	3.24			3.22			
G. C.			2.90	3.03	2.53	2.95			2.37	3.02		
C. C.			.51	.33	.96	.29			.46			
Hardness												
Br.	196	114	183	114	179	115	196	107	202	114	192	118
Sc.	35	33	39	34	40	34	40	31	39	32.5	36	34
Transverse	535	447	502	419	520	348	660	430	543	342	484	370
Deflection	.07	.08	.07	.05	.085	.08	.02	.09	.065	.085	.08	.09
Charpy Impact	23.8	25.6	17.2	20.4	16.3	29.1	14.7	16.4	26.4	25	23.8	15.9

Heat Treatment:	T-2. Heated to 790° C. (1450° F.) and quenched in water				T-3. Heated to 735° C. (1370° F.) and quenched in water			
Spec. No.	23 C. I.		34 C. I.		43 S. S.		44 C. I.	
	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.
Chem. Anal.								
T. C.							3.46	2.77
G. C.							2.84	2.66
C. C.							.62	.11
Hardness								
Br.	207	238	187	278	207	152	179	131
Sc.	35	55	35	61	39	42	36	39
Transverse	515	527	522	650	539	561	520	441
Deflection	.08	.06	.04	.02	.07	.085	.06	.095
Charpy Impact	21.6	27.3	20.1	29.6	25.8	33	24.4	22

Heat Treatment: T-4 (Heated to 870° C., and cooled slowly in furnace).

Spec. No.	9 C. I.		12 C. I.		15 C. I.		21 S. S.		26 C. I.	
Chem. Anal.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.
T. C.	3.15	3.24	3.42	3.04	3.32	3.36	3.19	3.06		
G. C.	2.75	3.36	2.53	3.16	2.43	3.46	2.20	3.10		
C. C.	.40	0.0	.89	0.0	.89	0.0	.99	0.0		
Hardness										
Br.							212	101	202	90
Sc.							39	31.5	39	31
Transverse							660	127	423	306
Deflection							.06	.08	.10	.09
Charpy Impact							20.5	27	19	18.8

Spec. No.	27 S. S.		28 C. I.		30 C. I.		31 S. S.		41 S. S.	
Chem. Anal.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.
T. C.			3.15	3.06			3.23	3.38	3.15	3.10
G. C.			2.57	3.24			2.43	3.42	2.44	3.02
C. C.			.58	0.0			.81	0.0	.71	.08
Hardness										
Br.	217	99	183	98	187	114	196	88	202	107
Sc.	41	33			39	31	38	35	40	31
Transverse					539	430	273	220	598	485
Deflection					.07	.09	.09	.09	.07	.08
Charpy Impact	20.9	20.3	27.3	17.1	18.0	17.5	20.4	15.2	28.6	27.1

Spec. No.	45 C. I.	
Chem. Anal.	Untr.	Tr.
T. C.	3.42	3.14
G. C.	2.70	3.34
C. C.	.72	0.0
Hardness		
Transverse		
Deflection		
Charpy Impact		

(*Continued on next page.*)

Table 14

(Continued from previous page.)

Heat Treatment:	T-5 (Heated to 735° C. (1370° F.) and quenched in oil						T-6 (Heated to 790°C. (1450° F.) quenched in oil			
Spec. No.	11 C. I.		35 C. I.		46 S. S.		16 S. S.		36 S. S.	
	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.	Untr.	Tr.
Chem. Anal.										
T. C.	3.33	3.12	3.41	2.76						
G. C.	2.53	2.80	2.39	2.76						
C. C.	.80	.32	1.02	0.0						
Hardness										
Br.	181	143			210	147	196	194	196	121
Sc.	38	37			38	37	39	43	40	43
Transverse	440	392			640	518	473	440		
Deflection	.06	.05			.06	.035	.07	.08		
Charpy Impact	18.8	16.3			25.6	30.0	29	28	25.3	36.7

Nos. 31 and 33 (Fig. 22) show specimen No. 23 C. I. relief polished at 100 diameters and etched with picric acid at 500 diameters respectively. Under relief polishing the graphite flakes appeared much larger and there was also some evidence of spheroidizing. The etched specimen showed a characteristic granular pearlite in micrograph No. 33.

Heat Treatment T-10: (Heated to 790 degrees Cent., quenched in oil and drawn at 700 degrees Cent.).

For this treatment specimens previously subjected to heat treatment T-6 were drawn at 700 degrees Cent. The distribution of the graphite as shown in micrograph No. 32 (Fig. 22) is very different from those untreated (micrograph No. 7, Fig. 12) and those subjected to heat treatment T-9. The graphite is in small flakes and spheroidized to a considerable extent. Micrograph No. 34 shows specimen No. 24 S. S. etched with picric acid at 500 diameters. The background matrix is granular pearlite, the same as in heat treatment T-9.

Summary

From the results of the tests on heat treated specimens in this research, the effect on the properties seem to be about the same on either grey cast iron or semi-steel. Table 14 gives a means of comparing all the results of the effects of heat treatment on both grey cast iron and semi-steel.

Summing up the results as given in Tables 13 and 14, the effects of heat treatment can be listed as follows:

Heat Treatment T-1: (Heated to 870 degrees Cent., held for three hours, and then cooled to black in 15 minutes in furnace, and then air cooled).

1. Total carbon is unaffected.
2. Combined carbon is reduced to around .30 per cent (reduction of 50-75 per cent).
3. Hardness is greatly reduced (from 200 to 155, Brinell, and from 40 to 35 Scleroscope).
4. Transverse strength is reduced (about 15 per cent).
5. Deflection under transverse loading is increased.
6. Impact property is greatly improved.
7. Practically all massive cementite is removed.

Heat Treatment T-2: (Heated to 790 degrees Cent. [1450 degrees Fahr.] and quenched in water).

1. Hardness is greatly increased.
2. Transverse strength is increased (5 to 20 per cent).
3. Deflection in transverse is decreased.
4. Impact strength is increased (25 to 40 per cent).

Heat Treatment T-3: (Heated to 735 degrees Cent. [1370 degrees Fahr.] and quenched in water.) (Below critical.)

1. Total carbon is reduced, probably due to surface decarburization.
2. Graphitic and combined carbon are reduced.
3. Hardness is substantially reduced.
4. Transverse strength reduced (5 to 15 per cent).
5. Deflection is increased.
6. Impact tends to increase (not marked).

Heat Treatment T-4: (Heated to 870 degrees Cent. [1600 degrees Fahr.] and cooled slowly in furnace).

1. No change in total carbon is shown.
2. Practically all combined carbon is graphitized.
3. Hardness is greatly reduced (nearly to that of ferrite).
4. Transverse strength is greatly reduced (20 to 30 per cent).
5. Deflection is increased.
6. Impact is reduced.

Heat Treatment T-5: (Heated to 735 degrees Cent. [1370 degrees Fahr.] and quenched in oil.) (Below critical.)

1. A slight oxidation of carbon is evident from reduction of total carbon.
2. Combined carbon is greatly reduced.
3. Hardness is reduced considerably.
4. Transverse strength is reduced (10 to 20 per cent).
5. Deflection reduced slightly.
6. Results on impact are very erratic.

Heat Treatment T-6: (Heated to 790 degrees Cent. [1450 degrees Fahr.] and quenched in oil).

1. Hardness is increased.
2. Slight reduction in transverse strength.
3. Tendency to increase impact properties.

Heat Treatments T-7 and T-8: (Heated to 870 degrees Cent. [1600 degrees Fahr.] and cooled slowly in furnace, reheated to 910 degrees Cent. [1670 degrees Fahr.] and quenched in water and oil, respectively).

1. Hardness greatly increased.
2. Graphite is spheroidized.

Heat Treatments T-9 and T-10: (Heated to 790 degrees Cent. [1450 degrees Fahr.] and quenched in water and oil respectively and drawn at 700 degrees Cent. [1392 degrees Fahr.])

1. Hardness reduced to that of original specimen.
2. Graphite spheroidized and granular pearlite or sorbite formed.

From the foregoing summary of effects of heat treatment it is seen that it is possible to greatly vary the physical properties through heat treatment. The temperature of heating, the time held at temperature, the rate and method of cooling are all very important factors to be considered. This study has shown that certain properties of both grey cast iron and semi-steel can be improved by heat treatment and they can also be almost ruined. A further study along the lines of this research would be a means to determine the proper heat treating temperature, the chemical composition that will respond best to heat treatment, the correct time of holding at temperature, and the proper rate of cooling. The properties desired will of course influence this to a considerable extent.

Conclusions

1. Proper heat treatment can greatly improve the general properties of grey cast iron and semi-steel. One of the important results is a uniform hardness and the elimination of massive cementite under annealing.

2. To properly heat treat, the correct critical temperature must be located and the temperature carried only enough above this to insure all parts being heated above the critical. This can be determined by ordinary thermal analysis.

3. The critical temperature of grey cast iron and semi-steel can be calculated with a fair degree of accuracy from the chemical analysis according to the following formula:

Critical Temperature = 730 degrees Cent. + (28 degrees X percent Si) — (25 degrees X percent Mn.)

4. Carbon is oxidized when subjected to a quench from just below critical temperature.

5. The best combination of properties was obtained by heat treatment T-1 (heated to 870 degrees Cent. [1600 degrees Fahr.], held for 3 hours, cooled to black in furnace and then air cooled). This was the heat treatment recommended by the Schaap process. This produced a uniformly soft product with only a slight reduction in strength properties.

6. Holding at high temperature for long periods of time or cooling very slowly such temperatures produces extreme softness, but also greatly reduces the strength properties.

7. To overcome the difficulty of dimensional changes, grey cast iron might be machined, and then subjected to a quench to produce hard iron which is not affected by intermittent heating and cooling below the critical.

8. The properties of both grey cast iron and semi-steel can be greatly varied by heat treatment and the possibilities of improving and controlling these properties offer great prospects of practicability. To do this additional systematic research is necessary for the coordination of chemical composition, physical properties, and correct heat treatment along with a study of the microstructures. This along with the use of the ferro alloys in cast iron and semi-steel will help to extend their field of usefulness and prevent somewhat the further encroachment of the other metals and alloys.

Acknowledgment

The author wishes to acknowledge the whole hearted cooperation and assistance of the members of the Experimental Laboratories, the Mechanical Engineering shops, and the various departments of the School of Mines. The author is also indebted to the foundry industries of the Twin Cities for their willing cooperation in furnishing all the needed test specimens for this research. The St. Paul Foundry Company, The American Hoist and Derrick Company, and The Minneapolis Steel and Machinery Company offered to furnish specimens but due to the limited time available bars were requested only from The Minneapolis Steel and Machinery Company. Especial recognition is accorded Dr. O. C. Harder for his many suggestions and assistance in proof reading, and also Miss Green for the assistance in the making of the many micrographs and slides. He also wants to acknowledge the assistance of C. H. Crust, foundry superintendent of the Minneapolis Steel and Machinery Company for his whole hearted cooperation and assistance.

WRITTEN DISCUSSION

G. F. Comstock, Niagara Falls, N. Y.

This paper seems to be quite an exhaustive study of the subject of heat-treatment of cast iron, and should be of considerable value to other workers in this field. On page 324, the author mentions light areas which appear in relief on unetched sections, and says they are evidently cementite. It has been the writer's experience that such areas are very often the phosphide eutectic and the author's micrograph No. 7 looks as if at least some phosphide was shown in it. Of course it is probable that cementite would have a similar appearance in an unetched section, but the presence of such light areas in relief should not be taken as evidence of the presence of free cementite.

At top of page 326, the author mentions graphite occurring next to massive cementite. This would be a rather unusual structure, but if what was taken for cementite was really ferrite, the structure would be quite normal. Micrograph No. 5, to which the above remark referred, appears to show ferrite and the phosphide eutectic, and it would be interesting to know if

the author has metallographic proof that free cementite was really present here in such close contact with graphite.

At the bottom of page 326 a "solid solution of some kind" is mentioned as occurring in iron quickly cooled in air after heat-treatment. This constituent resembled ferrite to a certain extent, but was found to be something else. The writer has noticed a similar structure in enameled cast iron, which of course was rather quickly air-cooled after the enamel was burned on at about the temperature used by the author. This constituent was assumed to be sorbite on account of its appearance and etching characteristics, and it is suggested that the unidentified areas in the author's micrographs 10 and 15 probably represent this substance. It is interesting to note that enameled cast iron is generally given, in the enameling process, about the same heat-treatment that according to the author's fifth conclusion gave the best combination of properties.

DISCUSSION

MR. PERRY: You have mentioned in paragraph 8, on page 342 of your paper about heating, or rather machining and then hardening. Did you have any idea of distortion there, and how much, for castings which would be possibly machined all over?

O. W. POTTER: We did not go into that very much. There is a chapter here on distortion under heat treatments, and the data are given in Table 12. We did not check that particular phase of it directly.

J. F. HARPER: I wish to express my appreciation of Mr. Potter's paper and would like to say that he has done a lot of very valuable work. There are one or two things I would like to bring out to the members assembled here, and that is the great danger of loss of strength and the reduction of hardness. In the higher anneals in the heat treatment or annealing of cast iron to reduce hardening, you always get a reduction of strength. Very often it is the desire of the foundryman to get a hard or coarse grained iron, and he works his analysis toward that end. It is then the desire of the machine shop to get a soft iron for machining qualities, and they call for an anneal which then causes a reduction in the strength, the very quality for which the analysis has been made.

The effect of time on the annealing temperatures, as shown in this paper, I do not believe has been gone into as thoroughly as it should be. The longer time that these temperatures are maintained, the greater effect they have upon the castings, their strength and hardening. The elimination of casting strains is a point that is of practical interest to many foundrymen, and I believe that that can be very easily attained by tem-

peratures that are sufficiently low to prevent a reduction of hardening. The matter of quenching of machine castings that the gentleman on the other side of the room touched on when he asked about distortion, has quite an effect, especially in castings which are of unequal section, and the results obtained from quenching or drawing of castings of unequal section are very often disastrous.

A MEMBER: I would like to ask Mr. Potter what temperature for reducing your strain did you have in mind? You mention reducing the strain with a low temperature; how low a temperature?

O. W. POTTER: That is more or less dependent upon your casting system or analysis, but roughly, I would say in the neighborhood of 1000 degrees Fahr.

A MEMBER: Would you not get some temperature strain even then?

O. W. POTTER: That would depend on the analysis and length of time that temperature is maintained in the casting.

MR. VECHTER: Some of the specimens show a reduction in total carbon. If some of those castings have been machined after heat treatment, there is danger due to this reduction in total carbon; there is too much oxidation of the carbon on the skin of the casting, so that you get into trouble so far as the machineability of the casting is concerned; in other words, the material will drag like a soft steel or very much deoxidized malleable iron.

O. W. POTTER: We did not take that particular feature to check. It was observed, however, that the oxidation was more noticeable at the surface than the interior of the casting.

CHAIRMAN ANTHES: This is a very interesting subject and one that I know will appeal to a great many. It is what we might call a search for the happy medium; we have to get the happy balance between our foundries and our machine shops, and also keep our specifications where they should be. This research work takes a great deal of careful study, hard work and concentration, and I am quite sure that the gentlemen who have been doing this research work would welcome any questions which would help them out or give them fresh ideas for further research. We have a lot of intelligent gentlemen here in the audience who have possibly some ideas on this question. Mr. Potter is here and is willing to answer any questions and I know will gladly accept any information which he thinks will be of advantage in further research.

J. T. MACKENZIE: I would like to offer a criticism of Figure 6, that apparently there was no deflection as to some units, no units stated on either side of the diagram, but as a matter of fact the deflection began as soon as the load went on. I do not see that Figure 6, as a standard, means anything except that there is a little greater change in the bending curve as the load goes on. It seems to me that the deflection units are not well chosen in relation to the load units in that figure.

O. W. POTTER: I accept that criticism, and it was already noted. There will be more information given when the paper is published.*

J. E. FLETCHER: I am sure the work that Mr. Potter has done shows evidence of a great deal of application. On our side we have done considerable work along these lines. There is one thing I would like to ask Mr. Potter and that is whether he has considered how vital the connection is with silicon and total carbon in a research of this kind? The sum of the total carbon and silicon content, as no doubt Mr. Potter has observed in his researches, is of very great importance. I just throw that out as a hint that some of these researches if plotted on a silicon plus total carbon content basis, might throw some further light on this subject. Nothing has been said, as far as I have read in this paper, as to the phosphorous and manganese content of the iron in question. On our side, of course we have to deal with very much higher phosphorous cast iron, as a rule. I would just like to hint that some of our researches, where higher phosphorous contents have been used, have shown that phosphorous has a very great effect, and I wonder whether Mr. Potter would tell us what the phosphorous content and the manganese content were in these irons? It is very difficult to speak offhand on a big paper of this description. I hope to contribute something further in writing.

O. W. POTTER: I believe in the early part of the paper there is a complete chemical analysis of all the specimens, the manganese content ranges from 10 to 50 points and the phosphorous is usually low. I think that will be found in the early part of the paper.

*Editors Note—Figure 6 as it appeared in the preprint has been replaced by Fig. 6 as it appears in this volume.

Nickel and Nickel-Chromium in Cast Iron

By Thos. H. Wickenden,[1] New York, and J. S. Vanick,[2] Bayonne, N. J.

The beneficial effects of the various alloying elements when added to steel have been pretty clearly established. It is in the line of natural evolution that the foundryman should seek similar improvements of his product. However, judging from the literature on the subject and the results secured by various foundrymen, the effects of these alloying elements on cast iron have not been clearly established and there has been considerable contradictory evidence. The comparison of cast iron with steel interspersed with graphite is not always a parallel one. In steel, many elements are limited to such small quantities that their influence is practically nil. In cast iron we have the same elements to deal with, but they are present in much wider percentages, thus resulting in many more metallurgical constituents whose effects in varying quantities must be considered rather than the elements themselves. These effects are further complicated by melting practice, pouring temperature and rates of cooling as produced by the section of the casting and the temper of the sand. The heat treatment of alloy steels plays an influential part in the results secured. The heat treatment of cast iron is limited, as many pieces produced in it are of such complicated section it is difficult to give them a simple anneal without danger of cracking. A review of the literature on the subject will show the conclusions reached by various investigators and in some cases a considerable divergence of opinion.

I. Conclusions Reached by Previous Investigators

The interest in this subject is not of recent origin, as patents can be found bearing on the subject dating back to the commercial adoption of nickel-steel in 1889. Patents issued in 1901 and

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1903 describe the effect of adding ½ to 40 per cent nickel to cast iron, producing alloys of greater strength, malleability and higher polish than regular cast iron, and mention its use for machine parts. Other patents are found mentioning the use of nickel to control chill, the addition of small quantities of chromium and nickel to chill white iron to increase the strength and toughness of rolls and wheels.

Guillet[3] was probably the first to describe, in 1907, the effects on the constitution of white and grey iron of the addition of up to 50 per cent nickel, noting two of the principal effects; i. e., the precipitation of graphite and the change in the matrix from pearlite to sorbite.

Dr. R. Moldenke[4] presented the results of tests with varying additions of special nickel-chromium pig iron to the mix This method of adding the alloy naturally confined him to practically one ratio of nickel and chromium in the charge, although the analyses of the test pieces showed quite a wide variation in the ratio of these two elements. Among the conclusions reached are found the following: Iron with nickel-chromium is stronger on transverse test but tends to show less deflection. Nickel-chromium definitely increases hardness with rising percentages. Nickel promotes the formation of graphite, while the action of chromium is just the reverse. Referring to its use in chilled rolls—added strength and elasticity are given by nickel. Greater depth of chill and hardness are produced by chromium.

Bauer and Piwowarsky[5] showed that nickel additions up to 1.98 per cent to a Swedish charcoal pig iron of very low silicon promoted the separation of graphite, and that the transverse strength was increased to a maximum of 30 per cent, the deflection being nearly the same. The compressive strength was increased 30 per cent, the tensile strength by 25 per cent and the hardness 18 per cent. The increase in graphite counteracted the normal effect of nickel. The addition of nickel up to 1.2 per cent improved the quality of cast iron for machined parts.

[3]L. Guillet. Comptes Rendus, Vol. *145*, p. 552, 1907.
[4]Effect of Nickel-chromium on Cast Iron. Trans. Mining & Metallurgical Engineer, Vol. 68, 930-952.
[5]The Influence of Nickel and Cobalt on the Physical and Chemical Properties of Cast Iron. Stahl u. Eisen, Vol. *40*, 1800-2 (1920).

Piwowarsky and Ebbefeld[6] showed that on a high carbon cast iron to which nickel was added a mechanical betterment of 25 to 40 per cent was secured. Additions of more than 1 per cent nickel showed no added improvement. With an increase of silicon in the cast iron the beneficial effect of nickel was lost.

Whitman[7] states in reference to cast iron used for resistance grids that when the amount of nickel is correct, it imparts toughness and pliability to the metal and helps to overcome the tendency of metal to run white and become brittle because of the rapid cooling action of the sand mold.

Swan[8] states that 4 to 5 per cent nickel may be used to advantage in piston iron, giving a product when machined of beautiful finish, extremely fine grained, possessing high strength, about 37,000 to 38,000 pounds tensile strength, and a uniform hardness.

Lowry[9] finds that nickel acts on the combined carbon. Both chromium and nickel have been shown to strengthen iron; when used together their activity in increasing the strength of cast iron is materially magnified. Nickel tends to create better machining qualities. It has been positively shown that a chrome-nickel iron has better machining features than a low silicon iron of equal hardness. Combined with this feature are the factors of hard, dense, strong castings whose soundness and texture are greatly improved. Further, nickel, like chromium, improves the chill in iron.

Campion[10] found that 1 per cent of nickel added to grey iron increased the strength but decreased the hardness.

The Cadillac Motor Car company has found that 1.5 to 2 per cent nickel results in increased hardness. The harder iron machines as easily as the iron without nickel and the nickel greatly increases the resistance of the iron to wear.

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[6]The Improvement of Cast Iron by the Addition of Nickel. Stahl u. Eisen, Vol. *43*, 967-8 (1923).

[7]Making 5 Per Cent Nickel Cast Iron Alloy in an Electric Furnace. Trans. A. I. M. E., 1921.

[8]Notes on Grey Iron for Automotive Castings. Trans. A. F. A., Vol. *31*, page 94, 1924. See also A. F. A. preprint 378, 1923.

[9]The Purchasing Agent, Nov., 1924.

[10]Influence of Some Special Constituents on Cast Irons. A. Campion, Foundry Trade Journal 20, 467 (1918).

Smalley[11] found that 0.5 per cent nickel gives a densening effect to grey cast iron. The change from the ordinary iron is one of dimensions of the graphite flake.

Levi[12] found that nickel tends to produce a regular distribution of graphite, reducing porosity.

Many other references might be quoted showing the diversified results secured. It is evident that the effects of nickel or nickel and chromium must vary with different percentages added in the same iron. Also that the effects of additions of constant percentage vary with irons of different analyses. It was with the idea of establishing more clearly the changing effects of these elements that the following series of tests were run.

II. Melting and Casting Practice

In the grey iron foundry there is a general opposition to results secured by melting in a crucible for comparison with iron run in a cupola. But for the experimenter, cupola iron is subject to many variables which make it difficult to determine what effect some particular element is producing. From a research standpoint, the alloy-modified compositions to be comparable, should be made from the same hot metal as the alloy-free base-melt. In order to lay a middle course, it was decided to melt the iron in a one-ton reverberatory furnace. The cooling rates were standardized by the use of dry sand molds and constant initial pouring temperature. Such questions as properties of the iron in various sections were to be answered by the test bars of corresponding section, while other items of importance should be answered by castings of appropriate pattern. These requirements were met as follows:

III. Procedure

(A) Melting. Mixtures of pig iron and scrap calculated to yield the desired silicon content were melted. The base composition was held by covering the molten charge with a thin layer of slag covered with ground carbon electrode. A reducing at-

[11]Effect of Special Elements on Cast Iron. O. Smalley, Foundry Trade Journal 26, 519 (1922).
[12]Properties of Cast Iron. M. Levi, Foundrie Moderne, Vol. 17, 82 (1923).

mosphere was produced by means of a smoky flame which was too cold to affect the composition. The furnace acted the part of the steel "mixer" and the difference in composition between the first and the last melt tapped was negligible. A typical charge follows:

Iron	Pounds
Machine Cast Pig	220
50:50 Malleable Pig 90:110 Si	880
Bessemer Pig	1400
	2500

A small amount (3.8 pounds) of ferro-manganese was added to bring up the manganese content, or additions of steel scrap were made to cut the carbon or silicon contents, while silvery pig (16 per cent ferro-silicon) was used for high silicon melts. The sulphur and phosphorus were kept low in all cases to avoid any variations in effects from these elements.

From the 2500 pound base-melt four taps were expected to be made and four crucibles filled with about 150 pounds of metal at each tap. The alloying metals in the form of "F" nickel shot or 70 per cent ferro-chrome were stirred into the crucible contents and the group of four crucibles heated for 15 minutes to bring them up to a suitable casting temperature. The short period of heating, the depth of the charge in the crucible and a thin film of slag over the metal, helped maintain the base-melt concentration of the elements in each melt. The 16 melts so obtained formed a parallel series with respect to their alloy contents in which each 2500 pound heat represented a new silicon or carbon base. The alloy compositions were usually held to the following program, although at times departures from this program were undertaken. Table 1 lists a typical series. Each melt was poured at 2500 degrees Fahr. (1370 degrees Cent.) and the row of molds always filled in the same sequence. A temperature drop of about 50 to 70 degrees Fahr. (28-40 degrees Cent.) was observed between the filling of the first and the last molds.

(B) Molding. Molds for strength or hardness test castings were made up in dry sand while other patterns of a general in-

formational character were made up in green sand. A typical row of molds would include some of the patterns listed in Table 2.

The molds were filled in the order in which they are listed above, then allowed to cool in the sand over night. All melts were run into patterns 1, 3, 4, 5, 8 and 10 while the remaining patterns were used principally for obtaining data upon special characteristics of certain melts.

(C) Testing. Tests were made upon the bars as cast, with the equipment of the research laboratory of The International

Table 1

Melt No.	Nickel Per Cent	Chromium Per Cent	Melt No.	Nickel Per Cent	Chromium Per Cent
1	None	None	9	.25	.20
2	.20	None	10	.40	.20
3	.40	None	11	.75	.30
4	.70	None	12	.75	.50
5	1.00	None	13	.75	.60
6	2.00	None	14	1.00	.40
7	3.50	None	15	1.00	.60
8	5.00	None	16	None	None

Table 2

PATTERNS USED IN TESTS

Pattern No.	Pieces on Pattern	Description	Purpose	Sand
1	1	¾" x 2" x 3" face. ¾" x 3" Chilled	Chill	Green
2	1	½" x ½" x 9 ft. Spiral	Fluidity	Green
3	4	½" x ½" x 12" Flat	Fluidity	Dry
3	4	½" x ¾" x 12" Flat	Transverse	Dry
4	4	½" x ¾" x 12" Flat	Transverse	Dry
4	4	½" x ¾" x 12" Flat	Transverse	Dry
5	2	½" x ½" x 12" in 1" Segments Tapered to Point	Fracture Fluidity	Dry
5	2	1½" wide x 12" long, stepped bar 1¼"—¾"—¼"—½" to edge	Fluidity Hardness	Dry
6	2	1¼" square x 1½" long	Pattern-Shrinkage	Green
7	3	¼" Thick—Tensile flat	Tensile	Dry
8	1	K Bar	Liq-Shrink	Green
8	1	K Bar (Inco)	Liq-Shrink	Green
9	2	1¼" Dia. round-headed	Tensile	Dry
10	3	1¼" Dia. round Cyl.	Transverse	Dry

Nickel company at Bayonne, N. J. Transverse tests were made upon the standard 1¼ inch diameter arbitration bar, over a 12 inch span; upon the ½ by ¾ inch bar, over an 8 inch span, and smaller dimensions, over a 6 inch span. Stresses were measured upon a machine of proper capacity, and deflections were measured with an Ames dial attachment. On the 1¼ and ½ inch bars the

test values on bars of the same melt usually checked within 10 per cent of each other. Bars of smaller dimensions varied over a larger range, being more sensitive to variations in thickness and cooling rate. The values given are the averages of two or more test bars.

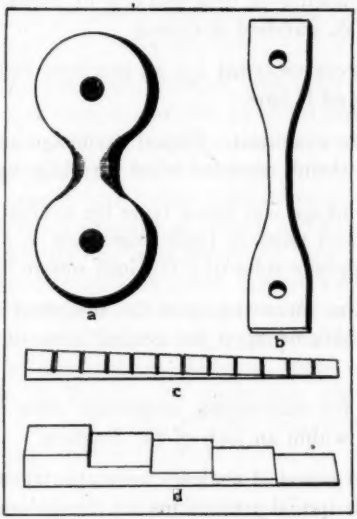

FIG. 1—PATTERNS USED FOR SOME OF THE TESTS. (A) TENSILE—AS CAST BAR, 1¼ INCH DIA. AT THE REDUCED SECTION BETWEEN THE EYES. HOLES DRILLED AFTER CASTING. (B) TENSILE—AS CAST-BAR. CAST IN ⅛, ¼ AND ½ INCH THICKNESSES. HOLES DRILLED AFTER CASTING. (C) SEGMENTED WEDGE, 1 INCH WIDE, ⅜ INCH THICK TO EDGE. NOTCHED AT 1 INCH SPACES. USED FOR OBSERVING FRACTURE, CHILL AND FLUIDITY. (D) STEP BAR, 1½ INCHES WIDE WITH 5 STEPS, EACH 3 INCHES LONG, AND STEPPED DOWN AS FOLLOWS: 1¼" TO ¾" TO ½" TO ¼" TO ⅛" TO EDGE. USED FOR HARDNESS VERSUS CROSS-SECTION TESTS AND FLUIDITY IN ⅛ INCH TO EDGE STEP

Chill bars were cast against a 4 inch cube of iron, split longitudinally, and the chill measured to .01 inch in terms of white, mottled or grey iron and their fracture modifications.

Fluidity was determined by the length of the ⅛ by ¾ inch spiral cast under a fixed head of metal, and by the filling out of the "tapered wedge," and tapered end of the "step bar."

Tensile properties were determined upon 1¼ inch round bars and flat bars of the shape shown in Fig. 1, drilled for the application of the load by means of a pin and yoke holder. These bars were used to economize on time and cost of preparation over that of the A. S. T. M. standard test piece.

Fractures were recorded for all test bars including the chill bar, wedge bar and K bars.

K bars were examined. Liquid shrinkage and the approximate size of the shrink recorded when shrinkage occurred.

Pattern shrinkage was taken from the average of four measurements upon two pairs of knife edges cast at a 12 inch actual span, into the opposite sides of a 1¼ inch square bar.

Hardness was measured upon the smoothed surfaces of the transverse test bars or upon the central zone of the "steps" in the "step bars."

Specimens for microscopic inspection were taken from the arbitration bars within an inch of the fracture.

Samples for chemical analyses were also taken from the arbitration bars with special precautions for the carbon sample.

The test procedure above was expected to yield data upon the following properties:

a. Chill.
b. Transverse strength and deflection.
c. Tensile strength.
d. Hardness vs. cross section.
e. Compression.
f. Liquid shrinkage.
g. Fluidity.

h. Pattern shrinkage.

i. Fractures.

j. Microstructure.

k. Miscellaneous.

IV. The Effects of Additions of Nickel on the Chilling Properties of Cast Iron

The effect of small additions of nickel has been difficult to determine in a quantitative way due to variations encountered in the other elements tending to obscure the effect due to the addition of small quantities of nickel alone. It was further complicated in these experiments by the contamination of some of the base melts with small amounts of nickel, absorbed from the crucible which apparently had been previously used for a nickel-iron, although caution was used to guard against this. Various tests were made to demonstrate the tendency for an iron to chill or show hard spots as undoubtedly the machinability of an iron is closely related to this property, although there may be no signs of white iron in the fracture. Among these tests was the pouring of a wedge bar and noting the distance from the end which was whitened; the chilling effect on the ⅛ by ¾ inch bars and by the casting of chill bars. The data secured by these methods show corresponding effects but the results from the chill bars showed more consistent values.

There is no question that additions of over 1 per cent nickel will make a marked reduction in the tendency of an iron to chill. Most of the tests with nickel below 1 per cent showed a similar reduction although it is not so marked and in some cases an increase in chill was shown. These data are given in Table 3.

In the case of Table 4 an increase was shown with .67 per cent nickel.

By re-grouping the data the effect of changes in the other elements can be brought out. A change in the total carbon makes the greatest effect on the chilling properties of the iron as shown in Table 5.

With a drop of 24 points in total carbon, the chill is increased .45 of an inch deeper as shown in Table 5.

As brought out in Table 6, a drop in carbon of 32 points increased the chill .85 of an inch. This is a greater rate of increase than above and it is a question whether the carbon becomes more effective in lower percentages or whether this small quantity of nickel is responsible.

In the presence of 1 per cent nickel, the change is not so marked (Table 7).

Table 3

Heat No.	Total Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of White Iron in Chill Bar in Inches	White and Mottled in Inches
60	3.59	1.02	.12	0	.70	1.30
62	x	x	.32	x	.60	1.05
64	x	x	.94	x	.55	1.10
66	x	x	1.10	x	.45	1.15
68	3.53	1.06	2.47	x	.30	.75
71	x	1.06	3.90	x	0	0

x(Not analyzed, but approximately the same as base melt.)

Table 4

Heat No.	T.C. Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of Chill in Inches	Depth of White and Mottled in Inches
214	3.67	1.38	.04	0	.05	.05
196	3.63	1.35	.67	0	.20	.90
202	3.61	1.48	1.23	0	.05	.05
204	3.66	1.43	2.36	0	0	0

Table 5

Heat No.	Total Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of Chill in Inches	Depth of White and Mottled in Inches
152	3.83	.96	0	0	.25	0.25
60	3.59	1.02	.12	0	.70	1.30

With a drop of 24 points in total carbon the chill is increased .45 of an inch deeper.

With a drop of 18 points in total carbon and 15 points in silicon, the chill is only increased .05 of an inch. It is evident that nickel has a stabilizing effect on the iron, making it less sensitive to chill due to variations in the total carbon and silicon contents.

With high total carbon, lowering the silicon is only mildly effective until approximately 1 per cent silicon is reached (Table 8).

With lower total carbon, lowering the silicon increases the chill more rapidly (Table 9).

The effects of additions of chromium by itself depends on the silicon content. A low silicon iron will show increased chill with small additions. A higher silicon iron will begin to show white iron in thin sections when 0.3 to 0.4 per cent chromium is added; above this point chromium is very effective. In the presence of

Table 6

DROPPING CARBON 32 POINTS INCREASES CHILL .85 OF AN INCH

Heat No.	Total Carbon	Si.	Ni.	Cr.	Depth of Chill in Inches	Depth of White and Mottled in Inches
190	3.79	1.30	0	0	.05	.05
192	3.47	1.34	.21	0	.90	1.30

Table 7

Heat No.	Total Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of Chill in Inches	Depth of White and Mottled in Inches
168	3.74	1.17	1.11	0	.40	1.00
66	3.56	1.02	1.10	0	.45	1.15

Table 8

Heat No.	Total Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of Chill in Inches	Depth of White and Mottled in Inches
154	3.84	1.68	0	0	0	0
160	3.86	1.28	0	0	.10	.10
152	3.83	.96	0	0	.25	.25

Table 9

Heat No.	Total Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Depth of Chill in Inches	Depth of White and Mottled in Inches
214	3.67	1.38	.04	.05	.05
60	3.59	1.02	.12	.70	1.30

small quantities of nickel, small quantities of chromium would show the chilling effect a little sooner. However, larger quantities of nickel will reduce it. The chilling effect of chromium and its reduction by nickel is very well brought out in Table 10.

It has been shown that above 1 per cent nickel is effective in reducing the chill in cast iron; interpreted in another way this means that nickel tends to break down the cementite into its con-

stituents, thereby reducing the combined carbon and increasing the graphite, confirming the observations of some of the other investigators. In white iron all of the carbon is in the combined state, the most of it being present as eutectic cementite. All iron with a combined carbon content above the eutectoid ratio of between .80 and .90 per cent must contain excess cementite unless the iron is austenitic. However, iron below the eutectoid ratio of combined carbon by chemical analysis may show the presence of free cementite in its microstructure. This carbon-rich material freezing last is rejected between the austenite grains. If the silicon is low or the cooling is sufficiently rapid to below A_r temperature, it will persist in the final structure and is not readily broken up until heated between 1200 to 1400 degrees Fahr. and slowly cooled.[13]

Table 10

Heat No.	Total Carbon Per Cent	Combined Carbon Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Depth of White Chill in Inches	Depth of White and Mottled in Inches
62	3.59		1.02	.32	0	.60	1.05
63	3.59		1.02	.32	.19	.75	1.25
66	3.56		1.02	1.10	0	.45	1.15
196	3.67	.76	1.35	.67	0	.20	.90
208	3.65		1.47	.66	.50	.65	1.45
216	3.67		1.50	.65	.66	.90	2.00
218	3.68		1.40	1.04	.61	.60	1.50
210	3.66		1.54	1.10	.51	.25	.50

The presence of nickel accelerates the disintegration of these carbides in the initial cooling. The question arises if an iron with the combined carbon below the eutectoid ratio will show a similar reduction in combined carbon with the addition of nickel. The melts of Table 11 will show this effect. The baths were saturated with carbon to produce a state of equilibrium.

This shows a reduction in the combined carbon of 9 points in the arbitration bar section for 2.85 per cent nickel. It must be remembered that 3 per cent nickel will reduce the carbon eutectoid ratio about this amount. It, therefore, appears that below the eutectoid ratio, the presence of nickel up to 3 per cent has only a mild tendency to reduce the combined carbon. This will be further illustrated in other data. Heat No. 17 with 4.17 per

[13]Annealing Grey Cast Iron. J. F. Harper and R. S. McPherran, Trans. A. F. A., Vol. 30, pp. 167-180, 1922.

cent nickel and 1.78 per cent silicon shows a reduction in both the total and combined carbon.

This tendency to reduce the total carbon with 5 per cent nickel or higher has been noted by Whitman in connection with his 5 per cent nickel-iron for resistance grids. "One of the peculiarities of this alloy of cast iron and nickel is a rejection of graphite from the metal when it is just melted, but when it is superheated, it again takes up the carbon thrown out at a lower temperature."

Table 11

	Heat No. 1[1]		Heat No. 11[2]		Heat No. 15[3]		Heat No. 17[4]	
	Total Carbon Per Cent	Combined Carbon Per Cent	Total Carbon Per Cent	Combined Carbon Per Cent	Total Carbon Per Cent	Combined Carbon Per Cent	Total Carbon Per Cent	Combined Carbon Per Cent
1¼ Arbitration Bar	3.63	.80	3.67	.72	3.67	.71	3.55	.55
½x¾ Bar	3.63	.80	3.78	.86	3.78	.78	3.52	.78
¼x¾ Bar	3.79	.82	3.82	.78	3.81	.79	3.70	.74
⅛x¾ Bar	3.83	.98	3.87	1.02	3.86	.91	3.72	.80

[1]Heat No. 1; Silicon 1.48 per cent; Nickel 0 per cent.
[2]Heat No. 11; Nickel 0.48 per cent.
[3]Heat No. 15; Nickel 2.85 per cent.
[4]Heat No. 17; Silicon 1.78 per cent; Nickel 4.17 per cent.

The same effect has been noted in making grids with a cupola iron; if all of the nickel is added in the cupola there is a loss in the total carbon tending to produce white iron. The best results have been secured by partial addition of the nickel in the cupola and the balance by addition in the hand ladle and pouring immediately. In this way the higher carbon is retained in the iron with its added greying effect.

V. The Effect of Nickel on the Strength of Cast Iron

Tables 12, 13 and 14 grouped according to silicon contents show the effect of increasing quantities of nickel and nickel-chrome on the transverse strength, deflection and hardness of the 1¼ inch arbitration bar as well as on thinner sections.

Iron With About 1.40 Per Cent Silicon (Table 12)

First considering the effect of nickel alone. An examination of the table will show that the strength shows a substantial increase with .76 per cent nickel but reaches a maximum with 1.23 per cent

Table 12

Heat Number	Total Carbon Per Cent	Combined Carbon Per Cent	Silicon Per Cent	Nickel Per Cent	Chromium Per Cent	Chill Bar Depth of White Iron in Inches	White and Mottled Depth in Inches	1¼" Arbitration Bar 12" Center to Center				8" Center to Center			¼" by ¾" Bar			¼" by ¾" Bar		
								Trans. Str. Pounds	Deflection In Inches	Tensile Strength Pounds	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	
214	3.67	.72	1.38	.04	0	.05	.05	3393	.132	21850	174	901	.102	174	348	.075	189	101	.121	
196	3.67	.76	1.33	.07	0	.20	.90	4100	.118	32600	205	1174	.096	217	394	.064	231	126	.113	
202	3.61	.62	1.48	1.23	0	.05	.05	4510	.142	31802	192	1161	.110	215	421	.068	222	106	.114	
204	3.66	.49	1.43	2.36	0	0	0	4470	.143	32212	203	980	.095	215	467	.125	231	198	.124	
212	3.62	.56	1.53	3.88	0	0	0	4288	.125	33325	228	1156	.095	214	410	.085	240	135	.176	
220	3.68	.49	1.53	4.89	0	0	0	4160	.188	29712	248	976	.114	269	419	.122	288	154	.205	
198	3.86		1.34	.24	0	0	0	3240	.123	30225	179	861	.094	192	367	.104	195	113	.131	
200	3.70		1.30	.37	.18	.30	.70	4250	.130	29400	199	1046	.087	217	396	.070	222	111	.100	
206	3.76		1.40	.87	.22	.20	.20	3910	.124	32200	207	966	.078	217	351	.064	231	95	.101	
208	3.65	.76	1.47	.68	.50	.65	1.45	4140	.105	24300	231	933	.065	223	302	.055	267	104	.093	
210	3.66	.80	1.54	1.10	.51	.25	.50	4773	.142	34400	223	948	.070	225	345	.059	231	102	.065	
216	3.67	.89	1.40	.65	.66	.90	2.00	3635	.116	29450	217	981	.056	241	365	.055	267	119	.084	
218	3.68		1.40	1.04	.61	.60	1.50	4220	.129		228	846	.058	255	205	.052	279	103	.061	

Table 13

Heat Number	Total Carbon Per Cent	Combined Carbon Per Cent	Silicon Per Cent	Nickel Per Cent	Chromium Per Cent	Chill Bar Depth of White Iron in Inches	White and Mottled Depth in Inches	1½" Arbitration Bar 12" Center to Center				¼" by ¾" Bar 6" Center to Center			¼" by ¾" Bar 6" Center to Center
								Trans. Str. Pounds	Deflection In Inches	Tensile Strength Pounds	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches
228	3.75	.59	2.03	.04	.10	0	0	3180	.132		163	499	.081	195	152	.174
236	3.70	.60	2.04	.14	.10	0	0	3010	.104	22950	179	466	.060	196	203	.147
224	3.78	.51	2.05	.40	.10	0	0	3352	.138	23487	163	449	.060	219	146	.182
226	3.63	.47	2.00	1.00	.10	0	0	3400	.134	23275	183	432	.063	224	115	.105
234	3.73	.67	2.10	2.13	.10	0	0	2960	.068	25050	196	401	.065	234	130	.202
242	3.65	.62	2.10	3.29	.10	0	0	3010	.105	24225	179	421	.067	238	173	.291
250	3.55	.68	2.10	5.03	.10	0	0	2870	.115	28862	293	406	.062	321	156	.194
252	3.67		2.05	.12	.16	0	0	3440	.125	23125	163	428	.082	204	145	.153
222	3.65		2.06	.25	.19	0	0	3150	.123	24200	170	477	.103	222	147	.170
240	3.67		2.07	.36	.16	.03		3253	.127	27825	170	509	.087	259	118	.114
230	3.65		2.10	.41	.32			3470	.115	24500	179	437	.075	219	177	.166
238	3.62	.67	2.02	.76	.32	.01		4220	.128	25675	187	497	.080	231	114	.117
246	3.68		2.03	.77	.40			3580	.100	27925	192	446	.076	246	102	.124
244	3.81	.75	2.09	.88	.56			3640	.090	21500	207	479	.068	219	184	.164
232	3.71		2.09	1.12	.27			3133	.101	27000	192	467	.089	234	133	.124
248	3.60		2.02	1.22	.39			3420	.104	29762	212	403	.069	261	139	.164

Table 14

Heat Number	Total Carbon Per Cent	Combined Carbon Per Cent	Silicon Per Cent	Nickel Per Cent	Chromium Per Cent	1¼" Arbitration Bar 12" Center to Center				¾" by ¾" Bar 6" Center to Center			½" by ¾" Bar 6" Center to Center		
						Trans. Str. Pounds	Deflection In Inches	Tensile Strength Pounds	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches
254	3.47		2.56	0	0	2930	.128	20962	159	420	.078	201	177	.171
268	3.58	.44	2.44	.20	0	3070	.121	19450	170	463	.096	222	150	.173
270	3.46	.39	2.55	.41	0	3210	.123	19975	163	434	.092	222	190	.163
260	3.47	.44	2.41	.67	0	3170	.138	20612	166	411	.088	219	149	.177
258	3.36	.55	2.51	1.06	0	3110	.124	20237	163	484	.110	195	183	.230
262	3.29	.48	2.51	2.33	0	3007	.113	22637	187	472	.088	222	184	.184
276	3.65	.64	2.66	3.59	0	3420	.112	23325	217	441	.090	249	147	.262
278	3.28	.75	2.63	5.70	.27	3360	.162	27087	286	373	.107	327	188	.213
256	3.51		2.63	.24	.18	3060	.119	22250	170	417	.086	210	175	.159
234	3.46		2.77	.26	.21	3047	.099	22000	163	538	.107	195	142	.098
266	3.50		2.64	.33	.38	3440	.135	23325	170	503	.106	240	160	.174
272	3.42	.73	2.73	.83	.59	3410	.115	23975	187	433	.089	240	143	.143
280	3.50	.64	2.68	.85	.75	3080	.110	28700	196	438	.091	249	145	.151
274	3.44	.75	2.70	.85	.77	3460	.107	27437	212	463	.088	256	222	.113
282	3.50	.62	2.58	1.18	.53	3913	.108	27875	215	347	.061	267	222	.139
264	3.51		2.70	1.46		3730	.119	26975	203	451	.092	240	151	.179

nickel which shows an improvement over the base-melt of 33 per cent on transverse strength with improved deflection and 45 per cent increase on tensile strength. The hardness of the arbitration bar is increased 18 points. A substantial gain in strength is shown in both the ½ and ¼ inch section with both nickel additions. With higher additions, although the transverse strength is not further increased, the tensile values continue upward, reaching a maximum at 3.88 per cent nickel—a gain of 52 per cent over the base-melt. Maximum deflection is secured with 4.59 per cent nickel, the increase being especially noticeable in the ¼ and ⅛ inch sections.

With nickel and chromium together a substantial increase is found with .37 per cent nickel and .22 per cent chromium, and with good deflection. With 1.10 per cent nickel and .51 per cent chromium the highest values are reached with the arbitration bar, showing an increase of 40 per cent on the transverse and 57 per cent on the tensile strength. However, on the thinner sections with their more rapid cooling, this increase in strength is not maintained. The mixture is overbalanced by the chromium preventing the disintegration of the excess cementite resulting in lower deflection values. With straight nickel additions, the strength and deflection are better maintained. It is evident, therefore, that with castings of varying section the use of straight nickel is advantageous to secure the best results throughout. Considering melts 208 and 210 containing the same chromium, it will be seen that by increasing the nickel, the tendency to chill and form excess cementite is reduced and the strength is materially increased. A comparison of melts 216 and 218 will again illustrate this point.

Iron With About 2.0 Per Cent Silicon (Table 13)

With higher silicon the nickel is not as effective in increasing strength as in the iron of lower silicon. With this silicon content but lower total carbon the increase in strength by nickel additions is better maintained. With 1 per cent nickel the transverse strength shows a mild increase with good deflection but recedes with higher additions. However, the tensile strength increases up to 5 per cent nickel addition showing a good gain.

This is a peculiar condition often noticed with straight nickel additions and worthy of some analysis. In a transverse test, the outer fibre or skin of the test piece is subjected to the highest stress, the layers underneath are gradually stressed less until the neutral axis is reached. The surface of a casting is subjected to a slight chilling effect due to the initial contact of the iron with the cold sand resulting in a skin of high strength and not representative of the iron underneath. Increasing nickel additions lessen this chilling effect, resulting in decreasing transverse strength. However, on machined transverse test pieces or if the strength of a section is tested as a whole, as in tensile test, the strength is shown to increase.

At 2.13 per cent nickel the hardness is increased 33 points but it recedes again at 3.29 per cent and regains rapidly at higher percentages. In the ⅛ inch section the improved deflection should be again noted with 2 to 5 per cent of nickel.

The addition of chromium in proper proportion with the nickel results in increased transverse and tensile values. The highest transverse being reached with .76 per cent nickel and .32 per cent chromium, showing an improvement of 32 per cent over the base-melt. However, a larger proportion of nickel to chromium results in better tensile values, reaching a maximum in heat No. 248 with 1.22 per cent nickel and .39 per cent chromium, showing an improvement of 30 per cent.

Iron With About 2.60 Per Cent Silicon (Table 14)

It is apparent that an increase in silicon destroys the effectiveness of nickel in strengthening the iron unless means are taken to counteract it. The increase in strength or hardness is very mild until 2.33 per cent nickel is added when the hardness starts to increase as well as the transverse and tensile strength. The increase in deflection of the ⅛ inch sections should be noted; improvement being shown with 1 per cent nickel, reaching a maximum at 3.59 per cent nickel and still well maintained at 5.70 per cent, but here showing more prominently in the heavier sections. With 3.59 per cent nickel the deflection is improved 53 per cent over the plain iron; when cast in green sand this improvement

will be greater. The data substantiates the increase in toughness and flexibility secured in electrical resistance grids when made from 3½ to 5 per cent of nickel cast iron.

With the addition of chromium in increasing quantities to counteract the effect of silicon the strength is gradually raised until a maximum is reached with .85 per cent nickel and .59 per cent chromium; an increase of 35 per cent on transverse, and about the same on tensile. The deflection is slightly lowered but the hardness is substantially increased. A comparison of heats 272, 280 and 274 with the same nickel content will show the effect of varying proportions of chromium. It can be seen that if the ratio of chromium to nickel is too low the highest strength will not be secured. If the ratio is too high the strength is lowered with decreasing deflection.

Table 15

Si.	Ni.	Total Carbon	Combined Carbon	Tranverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent				Hardness
2.76	0	3.09	1.53	35.5	6.7	84.4	184
2.72	0.49	3.05	1.46	44.6	6.9	120.1	224
2.72	0.96	3.00	1.43	40.9	6.5	112.0	215
2.72	1.49	3.07	1.43	39.8	6.7	110.0	209
2.71	1.98	3.02	1.40	39.1	6.4	104.6	205

The statement was made above that on high silicon, low-carbon iron the increase in strength by nickel additions is better maintained. This is well brought out by data from Piwowarsky,[14] given in Table 15.

These data show an increase in transverse strength with .49 per cent nickel addition of 25 per cent and in tensile of 42 per cent with an increase in hardness of 40 points.

It might be considered that the improvement was entirely due to the effect of chromium. Further data (Table 16) by Piwowarsky [14] will throw light on this point.

Increasing the chromium addition to a high silicon iron shows a mild increase in strength but it is secured at a sacrifice of the

deflection. The hardness is increased roughly in proportion to the chromium content.

The effects of additions of nickel to the above chromium irons are shown in Tables 17, 18 and 19.

It is apparent that with a low chromium content the addition of nickel has a very mild effect. (Table 17.)

Table 16

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
2.76	3.72	.26	0	0	16.6	7.7	45.1	116
2.71	3.69	.32	0	.14	18.8	7.4	42.8	122
2.74	3.74	.33	0	.29	18.0	6.5	45.1	138
2.77	3.78	.57	0	.53	19.3	5.1	44.5	143

Table 17

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms Per Square Milimeter	Deflection in Milimeters	Tensile Strenth Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
2.71	3.69	.32	0	.14	18.8	7.4	42.8	122
2.72	3.72	.25	.21	.14	18.7	5.9	42.5	141
2.71	3.72	.23	.39	.13	19.1	6.1	45.8	135
2.77	3.71	.22	.75	.14	18.9	5.8	44.2	112

Table 18

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
2.74	3.74	.33	0	.29	18.0	6.5	45.1	138
2.80	3.67	.36	.20	.29	23.0	5.6	50.9	144
2.80	3.75	.37	.38	.31	24.8	6.3	55.0	139
2.77	3.76	.31	.74	.32	20.0	6.3	46.1	126

With .30 per cent chromium (Table 18) the addition of .38 per cent nickel shows appreciable improvement in both transverse and tensile strength.

With the addition of .75 per cent nickel to .50 per cent chromium (Table 19) the transverse is increased 56 per cent with improved deflection; the tensile 41 per cent with a decrease in hardness.

[14]Stahl u. Eisen, Feb., 1925, p. 37, "Improvement of Cast Iron with Alloy."

The lack of improvement in the first series is probably due to the fact that there is not sufficient combined carbon present for the alloys to act upon. When the silicon is lower or sufficient chromium is present to increase the combined carbon to around .50 per cent the alloys are much more effective.

Table 19

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinel
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
2.77	3.78	.57	0	.53	19.3	5.1	44.5	143
2.75	3.76	.56	.19	.49	24.4	6.0	53.1	152
2.79	3.69	.51	.40	.50	26.2	5.4	68.1	161
2.79	3.75	.48	.75	.48	30.1	6.1	63.0	131

Table 20

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms Per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
1.82	3.70	.44	0	0	18.5	8.6	46.5	132
1.80	3.76	.52	0	.14	20.8	8.7	46.0	133
1.82	3.78	.55	.20	.14	21.7	8.1	51.2	143
1.75	3.77	.47	.39	.14	17.1	6.5	49.1	120
1.81	3.72	.37	.72	.15	29.1	7.8	73.0	146

The lower silicon irons require less chromium to produce improved strength showing that a large part of the effect of chromium is to neutralize the effects of silicon. (Table 20.) With the addition of .72 per cent nickel to .15 per cent chromium the transverse is increased about 40 per cent, the tensile 58 per cent and the hardness 13 points. With the addition of .70 per cent nickel to .30 per cent chromium (Table 21) the transverse is increased 58 per cent, the tensile 45 per cent and the hardness 49 points.

With the addition of .74 per cent nickel to .50 per cent chromium (Table 22) the transverse is increased 50 per cent, the tensile 42 per cent and the hardness 33 points.

It can be seen from the numerous data given that a great variety of effects can be produced by the addition of nickel and chromium to iron.

Small additions will refine the size of the graphite and result in a corresponding increase in strength and hardness. Higher proportions of these alloys are required to produce maximum effects but several basic conditions must be fulfilled to do this. The elements affecting combined carbon and the rate of cooling, which is, of course, dependent on section, must be balanced to result in the presence of approximately .50 to .80 per cent combined carbon for the alloy to act upon in order to produce maximum results.

Chromium, largely through its ability to increase the combined carbon, will add strength and corresponding hardness to an iron, up to a point where free cementite is formed. Further additions result in lessening the strength and deflection but rapidly

Table 21

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
1.81	3.71	.65	0	.28	21.5	7.7	51.1	141
1.87	3.67	.62	.20	.29	23.1	7.0	56.0	147
1.69	3.85	.58	.41	.29	26.7	6.5	57.2	145
1.70	3.76	.47	.70	.32	34.0	7.6	74.3	190

Table 22

Si.	Total Carbon	Combined Carbon	Ni.	Cr.	Transverse Strength Kilograms per Square Milimeter	Deflection in Milimeters	Tensile Strength Kilograms per Square Milimeter	Brinell
Per Cent	Per Cent	Per Cent	Per Cent	Per Cent				Hardness
1.68	3.60	.80	0	.48	23.0	7.4	53.8	153
1.74	3.61	.72	.21	.49	26.2	5.7	63.1	158
1.75	3.68	.72	.39	.49	31.4	6.2	76.2	174
1.73	3.76	.65	.74	.48	34.6	7.7	77.0	186

increasing the hardness due to excess cementite. These same characteristics increase the tendency of the iron to chill.

Nickel tends to break down the excess carbide to the eutectoid ratio, acting only mildly beyond that point; it, therefor, reduces the tendency of the iron to chill. When the combined carbon present is low, nickel can only act to slightly strengthen the ferrite with but little increase in hardness. When the combined carbon is higher, nickel acts to retard the formation of pearlite, resulting in

sorbite or one of the higher structures. This results in increased strength and hardness.

Silicon in increasing quantities not only acts to break down the eutectic cementite but also the cementite below the normal eutectoid ratio and forces what combined carbon is present into the pearlite state. It is on these points that the action of silicon differs from nickel, and makes the effect of nickel inoperative in the high silicon iron. Therefore, in using nickel when strength is desired, the silicon should be reduced to the lowest practical point; the nickel will prevent the iron from chilling and at the same time has an opportunity to exert its greatest influence in increasing the strength. The hardness would be uniformly increased and good machining would be preserved.

Nickel and chromium together act more powerfully than either one separately in retarding the formation of pearlite, a fact well known with the nickel-chromium steels, therefore resulting in maximum strength and corresponding hardness. The proper balance must be maintained; if the combined carbon in the iron is normally near the eutectoid ratio the chromium should be low and the nickel high to avoid chill and hard spots; if the combined carbon is normally low the chromium ratio should be higher, or other means used to raise the combined carbon. If the silicon is high, chromium is necessary to counteract its action to form pearlite before the full strengthening action of the nickel and chromium is effective.

It is the desire of the foundryman to run as few mixtures of iron as necessary to cover the numerous requirements of his various castings. Some may be of thin sections requiring iron to prevent chilling, or have maximum toughness. Others may require high strength; high hardness and wearing properties; dense fine-grained castings to withstand pressure, and in most cases good machinability. With a single iron and the proper addition of nickel or nickel and chromium, the usefulness of the iron may be widely extended in meeting these requirements.

When a high silicon iron of 2.50 per cent silicon or higher is being run in very thin sections the addition of nickel will aid in

preventing chill spots and thereby aid in securing machinability. For piston rings or thin wall pistons from .75 to 1.50 per cent is being used for this purpose. For extreme flexibility 3½ to 5 per cent nickel should be added, as in thin electrical resistance grids. If increased hardness is essential in a heavy section, .50 per cent nickel and .50 per cent chromium would prove effective, while in thinner sections the ratio should be changed by increasing the nickel to .75 to 1.00 per cent with the same chromium to maintain the machinability as well as the deflection and maximum strength.

When a medium silicon iron of around 2 per cent is being run in thin section, add 1 to 3 per cent nickel to prevent chilling and maintain machinability, and for great flexibility 3½ to 5 per cent. To increase the hardness combined with good machinability 1 to 2 per cent of nickel will give results in many cases and is especially desirable in castings of varying section. Other conditions may require .75 to 1.00 nickel with .2 to .3 per cent chromium and in heavy or slowly cooled section increase the chromium to .40 per cent or higher. This condition will also apply to securing maximum strength.

When a low silicon iron of around 1.25 per cent is being run, the addition of 1 to 3 per cent of nickel or higher will prevent the formation of white iron in thin sections or on the edges. It will result in an increase in hardness, wearing properties and strength in the body of the casting. In heavy castings of uniform section .75 to 1 per cent of nickel with .2 to .3 per cent chromium may be desirable.

VI. Hardness and Its Relation to Machinability of Cast Iron

The Brinell hardness of a piece of cast iron is really a composite result of the hardness and condition of the various constituents. Two irons of the same hardness do not indicate the same condition of the metallographic constituents. One may have a matrix compose of segregations of free-cementite and pearlite, but due to the nature of the graphite the Brinell hardness may be the same as the other piece showing a matrix of sorbitic structure without free-cementite. Consequently these irons will not have the same machinability as the one showing free-cementite, which

is extremely hard, will dull the tool quickly and machine with difficulty, while the other iron will machine without trouble. The presence of nickel in increasing quantities will tend to prevent the formation of cementite and, as pointed out above, its hardness is secured by changing the pearlite toward a higher state, such as sorbite. This type of hardness is uniform and, therefore, nickel-irons can be machined at a much higher hardness than an iron containing free cementite.

As previously pointed out, free cementite is not easily disintegrated unless heated to between 1200 and 1400 degrees Fahr. But annealing at these temperatures will result in lower strengths. The additions of a proper amount of nickel will eliminate this necessity.

Proof of these statements can be shown by examination of the micrographs of similar iron with and without nickel additions. This will be brought out later in the discussion of microstructure.

A number of tests have been made which prove the facts presented and a brief description of one will be cited. A set of 4 inch diameter cylinders, with internal steps each 4 inches long and wall thicknesses varying from 1 inch to ⅛ inch, were cast using iron from the same large ladle and adding "F" nickel shot in a hand ladle to give ½, 1, 2 and 3 per cent of nickel, as well as casting without additions for comparison. The iron contained about 1.40 per cent silicon. The hardness of the various pieces and sections is shown in Table 23.

The cylinders were placed in a lathe and machined on the outside face, starting at the thick end. A 1/16 inch cut was taken, the feed and speed remaining the same in each case.

The cylinder of plain iron machined with difficulty, requiring regrinding of the tool three times before the chilled ⅛ inch section was reached which was entirely chilled white.

The cylinder with ½ per cent nickel was machined to the ⅛ section before dulling and after regrinding, machined up to the chilled section.

The cylinder with 1 per cent nickel was machined to the chilled iron without regrinding.

The cylinder with 2 per cent nickel was machined the entire length without difficulty.

The tool was not reground for the cylinder with 3 per cent nickel which was also machined its entire length without difficulty, although it has a higher Brinell hardness in all sections than

Table 23

BRINELL HARNESS

Piece No.	Ni Per Cent	1 Inch Section	½ Inch Section	¼ Inch Section	⅛ Inch Section
1	0	234	255	255	4 inch White Iron
2	½	244	255	255	2 inch White Iron
3	1	248	255	255	¾ inch White Iron
4	2	255	269	269	½ inch White at End
5	3	269	269	269	Free from White Iron

Table 24

LOW SILICON IRONS

Melt No.	T. C. Per Cent	Si. Per Cent	Ni. Per Cent	Cr. Per Cent	Strength in Compression—Pounds per Square Inch Test 1 (As Cast)	Test 2 (As Cast)	Test 3 (As Cast)
28	3.53	1.16	0	0	67,500		
33	(x)	(x)	.48	0	74,500	76,400	
46	3.69	1.21	1.54	.67	88,100	84,500	
47	3.67	1.27	2.04	0	83,100		

(x) About the same as base melt No. 28.

					Test 1 (Machined)	Test 2 (Machined)	Test 3 (Machined)
190	3.79	1.30	0		93,600	90,200	
202	3.61	1.48	1.23		114,400	112,000	115,500
204	3.66	1.43	2.36		107,400	105,200	106,300
214	3.67	1.38	.04		89,500	95,200	

NOTE: Melts 190 and 214 are base melts. See data Table 12 for other test properties

Table 25

Melt No.	T. C. Per Cent	Si. Per Cent	Ni. Per Cent	Strength in Compression—Pounds per Square Inch Test 1 (As Cast)	Test 2 (As Cast)	Test 1 (Machined)	Test 2 (Machined)
154	3.85	1.68	0	87,900	94,100	86,600	88,100
158	3.81	1.70	1.70	105,200	102,700	102,000	100,840

the plain iron. The uniformity of the hardness in the sections of different thickness should be noted.

VII. Compressive Strength

Compression tests were made upon a few melts to touch upon the relation between the properties in compression versus those in transverse or tensile strength. Specimens machined to 1 inch

diameter by 3 inches long from arbitration bar castings or unmachined sections 3¾ inches long were used. In general, melts showing good transverse or tensile strengths, confirmed their superiority in compression tests. For example, in Table 24 the data from low silicon irons are given.

For a plain and 2.0 per cent nickel-iron we get the data of Table 25.

VIII. Liquid Shrinkage

"Does nickel increase the shrinkage?" is a question frequently asked by the foundryman. Apparently the large liquid contraction which pure nickel, nickle-chrome, and alloys of nickel-chrome-iron exhibit when cast, has carried its shadow into the iron foundry. Cast irons containing less than 5 per cent nickel do not follow the course of the alloys mentioned, but resemble the solvent or base melt cast iron in behaviour. In many cases the small additions of alloy seem to lessen the susceptibility to "shrinkage." The control of this property falls properly in the field of the molder and its undesirable effects can be overcome by skillful molding, or by altering casting design. In such cases the "liquid contraction" or shrinkage of the metal may become an important factor. It was felt necessary to demonstrate roughly the susceptibility to "shrinks" of alloy cast irons as compared to plain cast irons.

The method of deliberately producing "shrinkage" by means of "K" bars was resorted to. Two bars, each one inch thick and of similar design, were cast from each melt, broken across the crotch of the "K" and the fracture examined for the presence and dimension of "voids" or "shrinks." On account of the coarseness of this test, the data are not included in this paper. A general description is presented, instead.

In the results from "shrinkage" tests, silicon above 1.40 per cent was found to increase the shrinkage as well as chromium in excess of .30 per cent in low silicon or .50 per cent in high silicon, and nickel when in excess of 3.5 to 5.0 per cent. Since this effect varied with the silicon content, it is well to mention the relation of the alloy irons to the plain irons. The low silicon irons are not readily susceptible to "shrinkage" unless too low a silicon or

carbon content moves them toward the white iron form. Adding nickel to a total of 3.50 per cent together with chromium to .30 per cent failed to reveal "shrinkage" in the bars. With more chromium, the iron moves in the direction of white cast iron and begins to show a characteristic susceptibility to shrinkage. Nickel at 5 per cent or more exercises a "greying" effect, but the dilution of the carbon in the iron by the large amounts of nickel, reduces the ease with which it flows. Similar effects occurred for the 2.0 per cent silicon iron, except that the plain iron showed shrinkage voids which were reduced by additions of nickel up to 2.0 per cent with or without chromium up to .30 per cent. Larger amounts of nickel, or nickel and chromium, restored the "shrinks" to base melt dimensions at 3.50 per cent nickel and more than .30 per cent chromium.

The high silicon plain cast iron showed very large "shrinks" which were reduced by the addition of nickel under .80 per cent or nickel and chromium together under 1.50 per cent. When quantities of .50 per cent to 1.50 per cent of nickel and chromium were added, the best results appeared in the range of ratios of 3 : 1 to 3 : 2 with the chromium not exceeding .50 per cent.

The evaluation of the "shrinkage" susceptibility between irons differing but slightly in composition is a speculative problem but the discussion presented above is in general, in keeping with certain known facts. For example, the tendency for irons high in silicon to "shrink" is known as well as the greater susceptibility which white cast iron shows toward this same property. The solidification phenomena which underlie these two extremes are not the same. The lower carbon and silicon of white cast iron raises its solidification temperature and the absence of graphite eliminates a pressure-exerting impulse on the internal, entrapped liquid. The apparent solubility of gas or the high contraction of iron-silicon compounds during solidification seem to promote "shrinks" in the high silicon irons. Small quantities of nickel (under 3.5 to 5.0 per cent) do not encourage the above factors in either the low or high silicon irons. The amount of chromium added in any case should be less than .50 to .60 per cent; decreasing as the carbon or silicon decrease since its effects upon shrinkage are similar to those appearing in chilled iron, which is pro-

duced by lowering the carbon or silicon contents Lower carbon or silicon raise the solidification temperature of cast iron, thereby decreasing its fluidity.

Since the shrinkage or liquid contraction is dependent to a considerable extent upon the fluidity of the iron especially in the process of feeding cavities from the gate or riser reservoirs, the "fluidity" may be regarded as an important supplementary property.

IX. Fluidity

Several methods were employed in an endeavor to determine the "fluidity" of the irons. These methods included the pouring of a 9-foot long flat, spiral of ¾ by ⅛ inch section and the measurement of the extent to which the tapered ⅛ inch thick ends of the "step-bars" and "segmented wedges" "filled out" as well as the "filling out" of ⅛ by ¾ inch flats and ⅛ by ⅛ inch pins. A pouring temperature of 2,500 degrees Fahr. was adhered to for test purposes, unless higher temperatures were necessary. It might be mentioned at the outset that none of these methods succeeded in differentiating between small changes in alloy content within the range of 0 to 3.50 per cent nickel and including .50 per cent chromium.

For the irons containing upwards of 1.40 per cent silicon no change in flow or filling out between alloy irons and plain irons could be detected, although a general improvement in "fluidity" was observed as the silicon content increased.

The pouring temperature and the carbon content of cast iron are known to affect the "filling out" of the molds, more than the addition of nickel within the 5.0 per cent limit or chromium within the 0 to .50 per cent range. An effort to determine the minimum temperature at which iron at the bottom (in silicon content) of the grey iron series could be poured, was undertaken by casting a plain 1.20 per cent silicon iron and one containing 5.0 per cent nickel with the same amount of silicon, at 100 degrees Fahr. intervals from 2,700 degrees Fahr. down. All of the thin section patterns employed for the "fluidity test" filled equally down to 2,400 degree Fahr. At the next 100 degrees Fahr. drop

to 2,300 degrees Fahr. both plain and alloy irons failed to "fill out" with a slight advantage in favor of the plain cast iron. Incidentally, the test included molds which were gated by openings occupying 25, 50 and 75 per cent of the cross section of the bar. It is interesting to note that the influence of the size of the opening between casting and runner was not felt until 2,300 degrees Fahr. was reached, at which temperature a slight advantage for the larger openings was detectable.

It is well known that a decrease in carbon raises the solidification temperature. With the carbon lowered to 2.50 per cent carbon, irons carrying up to 5.0 per cent nickel will "fill out" as well as the higher-carbon grey irons if the pouring temperatures are raised 100 degrees Fahr. to 2,600 degrees Fahr.

With the silicon in the grey iron range and the carbon at 3.00 to 3.25 per cent and up, no appreciable change in fluidity was observed. A small decrease of the order of .25 per cent carbon in the total carbon induced more sluggishness than a change over the range of 0 to 5.0 per cent nickel. With a carbon content initially at 3.60 total carbon and silicon at 1.0 per cent and both elements being diluted by nickel additions, all of the "fluidity" patterns filled out up to 5.0 per cent nickel with the carbon content at 3.10 per cent and the silicon at .95 per cent.

X. Pattern Shrinkage or "Contraction"

No consistent relation between the compositions and "pattern shrinkage" could be developed from the measurements made, and a more detailed study of this property was not undertaken. For practical purposes, the usual tolerances allowed for grey cast iron are satisfactory, although the average values lie nearer .150 inches per foot or slightly higher than ordinarily allowed for grey cast iron. A typical set of measurements upon ½x¾x12 inch bars is given in Table 26.

On 1¼ inch square sections the results of Table 27 might be expected.

XI. Fractures and Relation to Structures

One of the foundryman's routine requirements is to produce iron with a "close-grained" fracture. The "close grain" is merely

a very rough index of the state of division of the graphite in the casting. Irons rich in carbon and with the proper silicon content are generally black in color, and blend into the lighter tones as the carbon decreases. Silicon acts in the same manner. The irons richer in silicon in a group of equal carbon content will show darker colored fractures. An increase in either the silicon or carbon content is usually revealed by a coarsened texture which is accompanied by a higher luster; such fractures might be called "shiny-black." When the graphite is coarse, the shiny or bright luster indicates the coarsened texture, while the color varies with the amount of carbon or silicon present.

Table 26

3.25 to 3.50 per cent C; 1.0 per cent Si. Per cent Nickel	Shrinkage Inches per Foot	3.25 to 3.50 per cent C; 1.50 per cent Si. Per cent Nickel	Shrinkage Inches per Foot
0	.145	0	.170
.29	.200	.50	.141
2.47	.128	1.54	.170
3.21	.168	3.55	.176
3.90	.132		
4.87	.112		
9.49	.120		
16.07	.150		
Average	.144	Average	.164

Table 27

Heat No.	Total Carbon Per Cent	Combined Carbon Per Cent	Mn. Per Cent	P. Per Cent	S. Per Cent	Si. Per Cent	Ni. Per Cent	Average Shrinkage Inches Per Foot
152	3.83	.79	.77	.18	.035	.96	0	.126
156	3.89	.83	.69	.10	.023	.88	2.40	.107
154	3.85	.69	.80	.13	.026	1.68	0	.118
158	3.81	.64	.80	.13	.013	1.70	1.75	.114

Fracture features are rough indices of the properties produced by the alloys, since an entire group of melts may reveal relatively similar fractures. Differences in graphite flake dimensions may be influenced by the gas content of the metal[15] and gas pressure in the mold, while in actual foundry practice the temper of the sand, pouring temperatures, casting sections, and other factors become operative. These factors, if not recognized, may obscure the effects of the alloys and receive the blame for poor fractures.

[15]Honda and Murakami. Sci. Reports. Tohoku Imperial Univ., Vol. 10, 1921, p. 273.

General features of the fractures might be summarized in the following list:

(a) Shiny black or average grey.

(b) Dull black or dull grey.

(c) Dull black or dull grey edges.

(d) Dull black or dull grey spots.

(e) Networks of several forms and intensity along the edges.

(f) Chilled edges, in the thin sections.

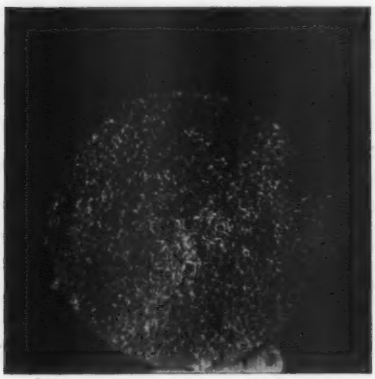

FIG. 2—BRIGHT NETWORK IN THE FRACTURE OF AN ARBITRATION (1.25 INCH DIA.) BAR, CONTAINING TOO MUCH CHROMIUM—MAGNIFIED 1.8 DIAMETERS.—MELT NO. 208. T. C. 3.65; C. C., .76; Si 1.47; Ni .66; Cr. .50; SEE FIGS. 6 AND 7 FOR DETAILS

Their relations to compositions and microstructure follow:

(a) The plain cast irons usually show a shiny black, shiny grey or fine textured fracture, depending upon the graphite flake size, shape and distribution. The microstructure of a plain cast iron with a good fracture could be represented by the structures

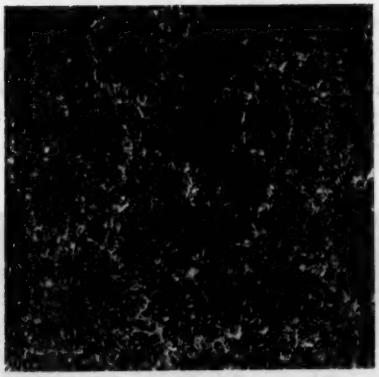

FIG. 3—SECTION NEAR THE EDGE OF A PLAIN, LOW SILICON IRON, REVEALS A FEEBLE NETWORK WHICH PENETRATES FOR A DEPTH OF ⅛ INCH AND THEN FADES OUT. IT CONSISTS OF A RESIDUE FROM THE EUTECTIC (CARBIDE) CEMENTITE. MAGNIFIED 50 DIAMETERS. MELT 152. T. C. 3.83; C. C., .79; Si .96; Ni .0; Cr. 0. ETCHED WITH 5 PER CENT PICRIC ACID

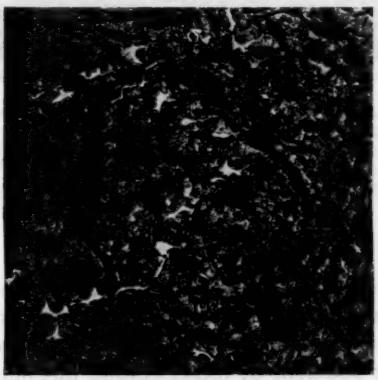

FIG. 4—SAME AS FIG. 3, MAGNIFIED 100 DIAMETERS, SHOWING SOME GRAPHITE CUTTING THROUGH THE IRON CARBIDE MESHES, BUT GENERALLY CURLED UP WITHIN THEM IN A "CABBAGE LEAF" PATTERN ETCHED WITH 5 PER CENT PICRIC ACID

shown in Figs. 4 and 5. In the plain irons tested above, fractures were usually of the shiny black or shiny grey type.

(b) One of the general characteristics of nickel and nickel-chromium upon iron initially showing shiny-black fractures is to deaden the luster, thereby indicating a refinement in the texture traceable to the more finely distributed graphite. Small quantities

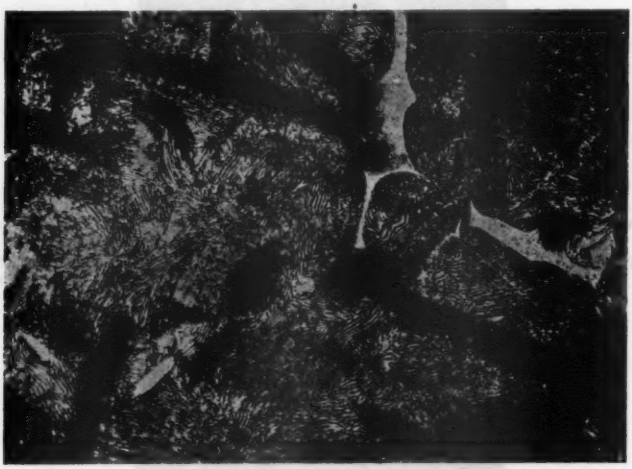

FIG. 5—SAME AS FIG. 4, MAGNIFIED 500 DIAMETERS, SHOWING THE POSITION OF THE CARBIDE NETWORK IN A PEARLITIC MATRIX. IN THE LOW SILICON, PLAIN IRONS, THE PEARLITE IS OF THE CONFUSED LAMELLAR TYPE AS ABOVE; AS THE SILICON INCREASES, IT INCLINES TOWARD THE MORE PARALLEL LAMELLAR FORM. AS THE NICKEL OR NICKEL AND CHROMIUM COME, THE STRUCTURE MOVES TOWARD THE SORBITIC FORM AS SHOWN IN FIGS. 7 AND 11. ETCHED WITH 5 PER CENT PICRIC ACID

of nickel or nickel and chromium may produce this effect. As the nickel content is increased to excessive amounts, the fracture returns to the shiny-black condition, indicating coarse graphite again. Further additions of nickel beyond this point do not improve the fracture. The refinement of the graphite flake is apparently induced in the nickel irons, by a stimulation of the crystalizing power of the primary crystalites or dendrites of austenite

which separate from the solidifying metal just before the formation of eutectic. They seem to break up the homogeneity of the solidifying solution enough to confuse the subsequent normal long-flake graphitization and force a graphitization around the nodes of the dendrites and within dendrite-enveloped, localized areas instead. Figs. 8, 9 and 12 are typical examples. The same influence is weakly manifest in the plain irons but it seems to

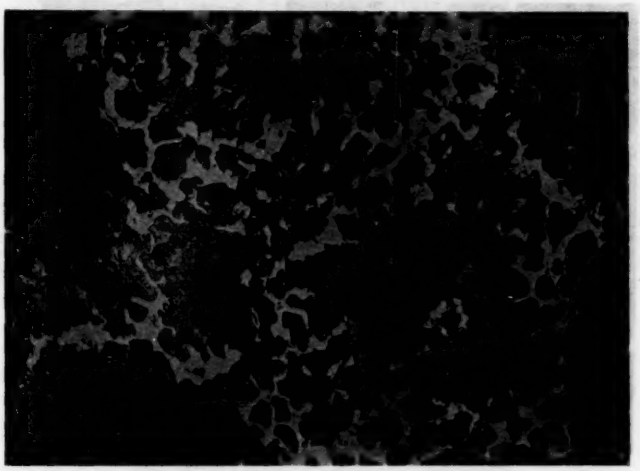

FIG. 6—A KNOT IN THE NETWORK STRUCTURE OF FIG. 2 REVEALS THE CURVED OUTLINE OF PARTICLES OF CEMENTITE RESIDUE. THE HONEYCOMB PATTERN INDICATES THAT IT REPRESENTS THE UNDECOMPOSED SKELEON OF THE EUTECTIC. MAGNIFIED 100 DIAMETERS. COMPOSITION SAME AS FOR FIG. 2. ETCHED WITH 5 PER CENT PICRIC ACID

lack the force necessary to produce a directional graphitization. The judicious use of nickel in encouraging this form of crystallization leads to an improvement in the size, shape and distribution of the graphite flakes or nodules. This breaking-up, in the manner described, of the normally coarse graphite flakes produces the dull-black or dull fractures which are associated with desirable physical properties.

(c) Dull black or dull grey edges are frequently developed by moderate amounts of nickel or nickel and chromium. The underlying microstructure consists of a cellular pattern of dendrites which envelop kernels of finely divided graphite plus ferrite or ferrite and pearlite This structure usually adjoins the surface layer of the casting and is apparently developed by the rapid cooling of the surface layers. Fig. 8 illustrates a typical occurrence.

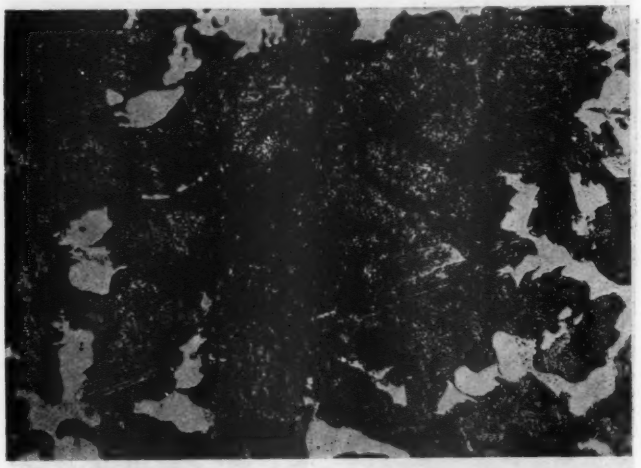

FIG. 7—SAME CASTING REPRESENTED IN FIG. 2. A SINGLE CARBIDE-ENVELOPED MESH, WITHIN WHICH GRAPHITE IS PRECIPITATED IN SHORT CURVED FLAKES THAT GIVE THE MESH THE APPEARANCE OF A SECONDARY GRANULATION. THE MATRIX APPROACHES THE SORBITIC CONDITION ALTHOUGH PEARLITIC MARKINGS REMAIN VISIBLE. NICKEL CONTRIBUTES TOWARD THE GRAPHITIZATION AND SORBITIZATION FEATURES. MAGNIFIED 300 DIAMETERS ETCHED WITH 5 PER CENT PICRIC ACID

The honeycomb pattern represents the faint network which is visible in the skin of nickel iron castings. The cell walls consist of dendritic cores apparently bent to form the cells which are filled with a finely divided mixture of ferrite, pearlite and graphite such as is shown at high magnification in Fig. 11. In some instances, the crystallization is so rapid that the dendritic cores are but feebly developed in the surface layers and a deep

FIG. 8—A FAINTLY VISIBLE MESH IS PRODUCED IN THE SKIN OF NICKEL CAST IRONS. IT CONSISTS OF A NETWORK OF DENDRITES, FREE FROM CARBIDE, ENCLOSING A GRANULATED OR "MACERATED" INTERIOR OF FERRITE, GRAPHITE AND PEARLITE OR SORBITE PARTICLES. SEE FIGS. 10 AND 11 FOR DETAILS. FROM 1¼ INCH DIA. BAR. MAGNIFIED 30 DIAMETERS. ETCHED WITH 5 PER CENT PICRIC ACID.—MELT NO. 204. COMPOSITION T. C., 3.66; C. C., .50; Si, 1.43; Ni. 2.36; Cr. NONE

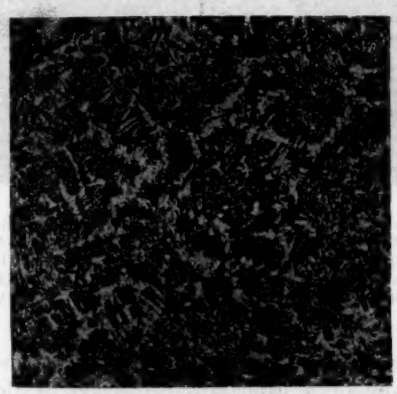

FIG. 9—CELLULAR PATTERN, SIMILAR TO FIG. 8, OCCURS IN THE INTERIOR OF NICKEL CAST IRON CASTINGS, IN DETACHED ZONES. ALSO OCCURS IN CHARCOAL PIG OR PLAIN CAST IRON, BUT IN MUCH SMALLER QUANTITIES AND LESS INTENSELY DEVELOPED. THIS STRUCTURE APPARENTLY CONFERS MUCH STRENGTH AND HARDNESS TO THE IRON. SEE FIGS. 10 AND 11 FOR DETAILS. FROM 1¼ INCH DIA. BAR.—MAGNIFIED 30 DIAMETERS.—ETCHED WITH 5 PER CENT PICRIC ACID.—MELT NO. 158. COMPOSITION T. C. 3.81; C. C. .64; Si. 1.70; Ni. 1.75; CO. NONE

penetration of fine particles of ferrite, graphite and modifications of pearlite, results, such as is shown in Fig. 9. This produces the dull black or fine black edge in which a network is very faintly observable.

(d) Dull spots in the interior of a fracture surface are really a modification of the dulled edges which have just been described. This fracture feature, like the dull-edges, is usually associated with the alloy irons, but it may occur in the plain irons,

FIG. 10—DETAIL OF FIG. 9 (ALSO APPLICABLE TO FIG. 8), SHOWING DENDRITIC NETWORK ENMESHED TO FORM A CELLULAR PATTERN IN WHICH THE CELL CONTENTS CONSIST OF A GRANULATED MIXTURE OF FERRITE, PEARLITE AND SMALL PARTICLES OF GRAPHITE. MAGNIFIED 100 DIAMETERS. COMPOSITION AND ETCH, SAME AS FIG. 9

too. This structure is illustrated in Fig. 9, 10 and 11. It consists essentially of a haphazard projection of dendritic knolls from a matrix of ferrite, graphite and pearlite or its harder derivatives. The dendrites endeavor to enmesh the matrix, thereby duplicating in appearance the cellular pattern occurring near the edges of a casting, as illustrated in Fig. 8. The structure is apparently produced by the rapid crystallization favored by

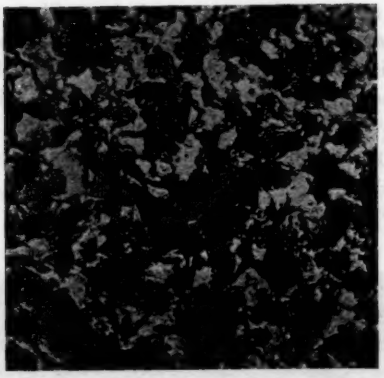

FIG. 11—DETAIL OF FIG. 10, SHOWING THE "MACERATED" MIXTURE OF PEARLITE, FERRITE AND GRAPHITE WITHIN A CELL OF FIGS. 8 OR 9. PEARLITE IS WEAKLY DEVELOPED AND CLOSELY APPROACHING THE SORBITIC STATE.—MAGNIFIED 500 DIAMETERS.—COMPOSITION AND ETCH SAME AS FIG. 9

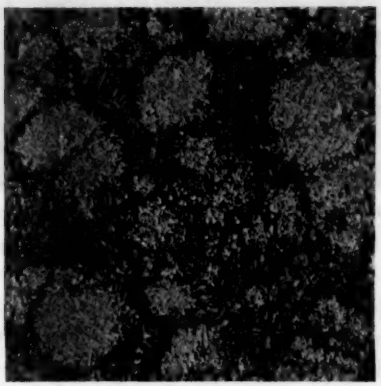

FIG. 12—CELLULAR FILLING COMPLETELY GRAPHITIZED IN PORTIONS OF THE DENDRITE ENMESHED ZONES OF A LOW-ALLOY CAST IRON. APPARENTLY THE ULTIMATE FORM OF DECOMPOSITION IN MESH OF THE FIG. 9 TYPE.—MAGNIFIED 30 DIAMETERS.—MELT NO. 252. COMPOSITION T. C. 3.67; Ni. 12; Cr. 16. ETCHED WITH 5 PER CENT PICRIC ACID

undercooling of an almost eutectic solution. Since nickel obstructs the transformations in steel and induces phenomena there akin to undercooling, similar effects might be expected during solidification. The undercooled, or alloy-inhibited solution solidifies rapidly, throwing up a mesh of austenite dendrites around eutectic kernels which commence to graphitize almost immediately. Under conditions favorable for graphitization, the entire eutectic kernel will decompose into a mixture of graphite and ferrite. Figs. 12

FIG. 13—DETAIL OF FIG. 12, SHOWING FERRITE AND FINE GRAPHITE ENCLOSED BY THE DENDRITE MESH. MAGNIFIED 200 DIAMETERS. ETCHED WITH 5 PER CENT PICRIC ACID

and 13 illustrate the ultimate state. This structure may occur in plain irons, containing about 2.0 per cent silicon, but its development in detail as well as in volume is much less extensive. In the fracture, it is often expressed by the "dull-black cores, "dull black spots," "dull-black edge" or the corresponding "'fine-grained black" portions or fractured bars. The black tone resembles that of good black-heart malleable iron; the texture which is responsible for the "dullness" is considerably finer. Mindful of its

microstructure, the resemblance to malleable cast iron is consistent. Very good properties may be anticipated from fractures showing these features.

(e) In low carbon or low silicon irons, a bright "network" in the fracture may be seen when the nickel or chromium content reaches sizeable proportions. The effect is not unknown in plain irons but it is less likely to appear. This network is undoubtedly associated with the mechanism of solidification in all irons, but its history apparently differs with the composition of the iron. For nickel, this may occur at .50 per cent or more; for chromium at .20 per cent or more. In chromium irons the meshes are more intense and continuous. The cellular structure is sometimes found in base melts or plain irons, especially those low in silicon. These irons develop a shallow network capped by residual cementite in a matrix of pearlite cut up by graphite. Figs. 3, 4 and 5 illustrate a typical case. This structure may sometimes be detected as a distinct network in the fracture or in the polished and etched surface of plain cast iron. This type of network is poorly developed or absent in nickel irons but it does occur in nickel-chromium irons when relatively large amounts of chromium are present. The addition of nickel to an iron with this structure breaks down or completely eliminates the cementite network or its residual particles. The chromium bearing irons containing more than a small amount of that element (depending upon the silicon or nickel content) produce a network which is likely to penetrate deeply. With additions of chromium in excess of .50 per cent to a low (1.40 per cent) silicon iron a network of the form shown microscopically in Fig. 2 may be developed. The networks differ with the composition of the iron as has been mentioned above. When present in a faint or poorly developed form, their presence is associated with good physical properties. When too intense or thick, brittleness under flexure, or hard spots and machining difficulties are apt to occur.

(f) Chilled edges in thin sections disappear when nickel in sufficient quantity is added to plain irons showing them. In the case of nickel-chromium mixtures, too much chromium may destroy the balance and produce chilled edges. Chromium, by retaining carbon in solution, produces fractures which by their

lighter color resemble those of lower carbon irons. If chromium in excess of moderate amounts, say more than .20 to .30 per cent, be present in a low silicon iron, chilled spots or whitened edges are likely to occur in the thinner sections. The structures in sections showing chilled edges are the usual white iron eutectic in the white edges, grading off into various degrees of decomposition in the interior.

XII. Fracture Features of Three Silicon Irons

The irons in the three silicon ranges described in the data above were in general modifications of the usual grey iron types. A few notes abstracted from the data upon them, and referring in general to section of ½ to 1¼ inches in thickness, follow:

For the low (1.60 per cent Si) cast iron, base-melt fractures were coarse textured, shiny black. Nickel additions up to 3.5 per cent Ni produced fine-grained fractures of a dull-black color and revealed a faint network near the edges. Nickel in the range of .30 to .80 per cent refined the texture and introduced the first traces of network. Chromium additions in this range, intensified the network but did not alter the texture of the matrix Relatively large additions of chromium (in the region of .50 per cent) intensified the network and induced "mottling" or whitening in the thin sections. Nickel cast irons free of the chromium remained "greyed" in the thin sections.

In the 2.0 per cent silicon cast irons, fractures for all sections were generally of the fine-grained, dark grey type. A refinement in the texture occurred for nickel irons carrying .70 to 2.0 per cent of that element and in the nickel-chromium irons in the region of .75 per cent nickel and up to .40 per cent chromium. The same relation was maintained in the thinner sections except that an increase in the predominance of "chilled edge" fractures occurred for the thin sectioned (⅛ inch) bars, containing chromium.

In the 2.70 silicon cast irons, a general coarsening of the texture of the fractures was observed in comparison to the lower silicon melts. A refinement of the texture was observed for irons

containing about .80 per cent nickel and .40 to .75 per cent chromium. From the appearance of the fractures of this group of irons, nickel and chromium are necessary in a minimum ratio of nickel to chromium of 4 : 3 or a maximum ratio of 2 : 1 to produce the finest-textured fractures. Lower carbon or lower silicon contents would undoubtedly move these ratios in the direction of more nickel. The occurrence of the "network" pattern near the edges of the 1¼ inch diameter bars is confined entirely to the nickel-chromium bearing irons in this group.

The high silicon irons are commonly used for thin castings. The uniformly fine-grained fractures developed in the ⅛ and ¼ inch thicknesses account for the favorable position which this composition possesses in the thin sectioned castings of the resistance grid type to which nickel is added. Two cases of chilled edges out of 16 compositions were recorded in the very thin sections. Both cases appeared in chromium-rich, nickel-chromium irons. It might be well to mention, at this point, that excessively high pouring temperatures may assist in producing chilled edges in thin sections.

XIII. Microscopic Features of Alloy Cast Irons

In view of the information which is available regarding the effects of nickel or chromium upon steel, similar effects would be expected to occur in cast iron. This generalization is largely true. The structure of cast iron, as has been mentioned above, is frequently referred to as a "matrix of steel cut up by graphite flakes." While this description greatly simplifies the study, it wholly ignores the tremendous influence of silicon and the important effects of impurities upon the ultimate structure, to say nothing of solidification patterns which are common to all cast metals and especially significant in cast iron.

The influence of silicon upon graphitization is quite generally known. In the three silicon levels used in the base melts above, the flake coarsened in the high silicon iron but remained about equally fine in the lower silicons. In the low silicon iron, nickel refined the flake quite in keeping with the remarks above concerning the fractures. In addition, the iron carbide networks were

decomposed by the nickel if the carbon happened to be low, or chromium high. Illustrations of the structure of a .66 per cent nickel, .50 per cent chromium member are shown in Figs. 6 and 7. Increasing the nickel to 1.10 per cent with this same chromium content destroyed the cementite network. Little or no chromium is needed, in addition to nickel, to produce a refined flake structure, free of cementite and hardened to specific requirements. Structures of the 2.0 nickel cast iron (1.40 per cent Si) are referred to above, showing the characteristic nickel-iron network and the cauliflower form of precipitation of ferrite, graphite and pearlite enclosed by the network. The nickel iron network is very faint and practically free of carbide, as Fig. 8 shows.

At the next silicon level (2.0 per cent) the change in structure with nickel added took the form of an increase in volume and frequency of the macerated zones illustrated in Figs. 9, 10 and 11. Chromium contributed to this end and larger amounts, up to .40 per cent, with suitable additions of nickel were beneficial. The occurrence of ferrite films along portions of the graphite flakes demonstrated the greater graphitizing power of this and the higher silicon iron. Similarly, the further graphitization of the pearlite particles in the enmeshed portions toward a ferrite plus graphite end-product showed the influence of the higher silicon content.

The highest silicon level revealed the coarsened flake structure of the base melt with the flakes lined with ferrite, showing the greater graphitizing power of silicon. Structures of the type shown in Figs. 10 or 12 appeared frequently in the larger sections and expressed the influence of the alloys upon the crystalization during solidification. More chromium may be added to this composition before the iron-carbide network is developed. In the 1¼ inch sections the carbide occurred when .60 per cent to .75 per cent chromium was exceeded in the presence of slightly larger amounts of nickel. Since most irons of this base composition are used for thin sections, the cooling rate in sections thinner than 1¼ inches would exert a compensating effect and reduce the amount of chromium required appreciably. Very good structures appeared for the irons containing about .80 per cent nickel and .40 per cent chromium. The influence of comparatively large amounts

of nickel (3.5 per cent) in breaking up the solidification-structure patterns is worth further attention.

The relation of the structures to certain mechanical properties might be mentioned as well as important forecasts of their probable performances in machining or in service. The hardening of the iron by the nickel additions is a characteristic effect which is quite generally known. The structure moves up the pearlite toward martensite scale. The changes in hardness roughly chart the progress of this movement, although precautions should be taken to avoid accepting the hardness contributed by low carbon or high chromium in the form of cementite-mesh in place of the "solid-solution hardness" conferred by the nickel. A solid solution matrix can be developed with a comparatively uniform hardness. The improvement in machining properties which the nickel confers by breaking up the cementite network or eliminating cementite islands has also been touched upon. Hard spots are done away with. The same cementite network tends to promote brittleness in low carbon, low silicon or chromium-rich irons. This fact is partly revealed in "deflection values" of transverse tests. Finally, the service which steam or auto cylinder irons are called upon to do requires that they be free of the cementite particle or its network, to increase wearing properties. The deleterious effect of hard particles which may crumble away or become detached has been dealt with in other work. In Hurst's[16] work upon cast iron the influence of the fragmentation of hard particles of eutectic or phosphide is described. The cementite residue of the cast iron eutectic would possess similar characteristics.

A final mention might be made of the structure of thinner sections made of alloy irons. A reduction in the section of a casting accelerates the the cooling rate and accentuates cooling rate effects. As might be expected, the dimensions of the graphite flakes are reduced and the matrix moves up the pearlite toward the sorbite scale if alloys are present.

Irons containing large amounts of nickel have been neglected in the discussions and data above. The movement up the scale

[16]Wear and Antifrictional Qualities of Cast Iron. J. E. Hurst, Carnegie Scholarship Memoirs, Vol. 9, p. 59, 1918.

from pearlite toward austenite may be accomplished by the addition of amounts of nickel in excess of 5.0 per cent. Such alloys enter or can be manipulated by heat treatment through the martensitic or austenitic state and the special properties applied to industrial requirements.

XV. Cast Iron With Higher Percentages of Nickel

An examination of the constitutional diagram for nickel-steel will show that with a carbon content of .40 per cent the pearlitic structure will predominate when slowly annealed. With increasing additions of nickel the presence of martensite or its derivatives begins to make its appearance. With an addition of approximately 7.5 per cent of nickel the martensitic structure will predominate. As higher percentages of nickel are added the presence of austenite will begin to make its appearance until at approximately 20 per cent of nickel this type of structure will predominate. A more rapid rate of cooling or a higher percentage of carbon has a similar effect on the structure to adding a higher percentage of alloy.

These same changes take place in the structure of cast iron when nickel is added. When iron is examined in the "as-cast" condition, the structure of the matrix will depend on the rate of cooling. Large sections will cool through the critical temperatures at a rate closely paralleling that for slowly annealed steel and will, therefore, require the full percentage of nickel to show up the characteristic structures and properties; smaller sections cooling more rapidly will show the characteristic of the varying size with smaller percentages of nickel additions. In fact, with cast iron the rate of cooling is doubly effective as compared with steel, as a higher percentage of carbon is retained in the combined state which further accelerates the change.

An examination of Table 28 will bring out some of the various phases.

It will be noted that with straight nickel additions hardness is gradually increased until approximately 10 per cent of nickel is added. This apparently represents the center of the martensitic stage for the cooling rate encountered in the 1¼ inch test

bars. Heavier sections would undoubtedly require a higher percentage of nickel to bring out the maximum hardness. It will be noted that in the 1¼ inch section the hardness begins to decrease with further nickel additions, showing that the austenitic type structure is beginning to make itself felt. In the case of heat No. 90 with 19.23 per cent of nickel the rapid rate of cooling of the thinner sections has produced a lower hardness than the slowly cooled large section.

Nickel irons in the martensitic and austenitic range show many interesting characteristics which might be used to solve particular problems in many lines of industry. Due to the presence of graphite, this material can be machined without difficulty and does not give excessive shrinkage in casting, especially as higher graphite is present. With a lower silicon content, the amount of combined carbon will be increased resulting in higher hardness and less machinability. Resistance to corrosion is greatly increased and these irons show remarkable resistance to wear, resembling the manganese austenitic steels in this characteristic. The austenitic irons are non-magnetic and possess high electrical resistance. This phase of a nickel-manganese iron is covered by patents of Ferranti, Ltd., who are promoting its use for frames of large motors and generators to overcome the losses due to stray currents and as a substitute for brass castings.

As seen in Table 28 the addition of chromium greatly accentuates the hardness which it is possible to obtain. The greatest hardness of 578 Brinell is reached with 4.69 per cent nickel and .70 chromium. This is apparently the center of the martensite phase as secured on an 1¼ inch section; larger sections would require more alloy. This hardness is due to the fact that practically all of the carbon is retained in the combined state. Further additions of nickel and chromium show a gradual lessening in hardness, showing an increase in the percentage of austenite present with its characteristic softness and increased toughness. Heat No. 136 is typically characteristic of an iron in the transient stage between martensite and austenite, the 1¼ inch section showing a hardness of 319 while the smaller sections which were more rapidly cooled show considerably less hardness; 290 for the ½ inch section and 258 for the ¼ inch section, while the chilled specimen

Table 28

Heat Number	Total Carbon Per Cent	Combined Carbon Per Cent	Silicon Per Cent	Nickel Per Cent	Chromium Per Cent	Chill Bar Depth of White Iron in Inches	White and Mottled Depth in Inches	1¼" Arbitration Bar 12" Center			½" by ¾" Bar 8" Center			¾" by ¾" Bar 6" Center			¼" x ¾" Bar 6" Center	
								Trans. Str. Pounds	Deflection In Inches	Tensile Strength Pounds	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches	Brinell Hardness	Trans. Str. Pounds	Deflection In Inches
214	3.67		1.38	.04		.05	.05	3396	.132	21850	174	901	.102	174	348	.075	189	101	.121
212	3.52		1.63	3.88		0	0	4258	.125	33325	228	1156	.085	214	410	.065	240	135	.176
220	3.68		1.68	4.59		0	0	4100	.188	29712	248	976	.114	269	419	.122	288	154	.205
504	2.72	.68	1.60	6.62		0	0	2735	.131	25375	298	1040	.167	285	386	.132	280	150	.247
88			1.54	10.62		.50	.25	4220	.128		330	1274	.062	431	517	.112	388	160	.295
89			1.54	15.59		.15		3660	.175		201	996	.100	285	418	.141	258	191	.426
90	1.87	.54	1.63	19.23		.05		3150	.218		159	802	.144	146	343	.148	150	165	.773
71	3.20		.96	3.90				5157	.126		169	1082	.090	228	413	.109	249	90	.120
72	3.10	.29	.93	4.67			0	4960	.132		205	842	.110	289	318	.118	256	104	.164
130	2.86		1.15	3.82	.42	1.20	Bal.	4340	.064		281								
131				3.82	.70	All		5110	.064		444	1259	.056	570	552	.077	459	138	.181
132				4.69	.70	All		4630	.065		578	1226	.067	578	549	.065	474	127	.198
134				5.33	1.45	All		5020	.099		477	1286	.071	547	514	.084	402	154	.233
135				8.05	1.82	All		5670	.119		460	1257	.087	418	613	.113	327	168	.339
136	3.06	2.06	1.44	9.66	1.20	All		5860	.153		352	1210	.113	228	603	.181	258	190	.409
223	2.48		2.70	32.78	3.18	All		4320	.223	28450	187	1186	.185	170	417	.170	178		
221	2.51		1.95	43.73				2000	.304 to .780	14500	78	540	.246	71	164	.210	62		
													.584			.380			

showed a hardness of only 301 on its face. An iron of this type shows entirely opposite characteristics to the ordinary cast iron, namely; that you chill it to make it soft and anneal it to make it hard. Austenitic iron has considerable toughness and ductility as is shown by the increase in deflection. These bars do not break suddenly in the transverse test and the deflections shown are those secured on the initial break.

XV. Commercial Application of Nickel and Chromium in Cast Iron

One of the first applications was the use of 5 per cent nickel cast iron for resistance grids. Several valuable properties are secured. The electrical resistance of the grids is increased over that of ordinary cast iron and the variation in resistance is made narrower by its presence. The nickel prevents the metal from running white so that they may be cast in green sand molds. In these thin sections the increased flexibility and toughening effect of nickel is well brought out in the data. This, together with other experiments, have shown that for an ⅛ inch section the maximum flexibility is secured with between 3½ to about 5 per cent of nickel. The ¼ inch section shows a similar improvement but not to such a marked degree. This increase in toughness of the grids reduces the handling loss in the foundry and during transportation to a minimum. This reduction in loss more than pays for the cost of the nickel. A further saving is gained in the assembled resistance unit. If a grid breaks during transportation of the finished unit, considerable expense is involved to replace it and retest the unit.

Similar applications are found in other thin section castings. In small section piston rings 0.75 to 1.25 per cent nickel is being used with good effect; the castings show a finer grain, increased toughness to breaking, improved machinability and wearing properties. A higher percentage of nickel apparently lowers the yield point of the iron permitting it to take a permanent set before breaking which is not desirable in this case. On larger size rings, the best results have been secured by lowering the silicon content over that normally used by 0.20 to 0.40 per cent when straight nickel is used or if this is impractical due to other uses

of the mix, make an addition of nickel and chromium. Locomotive piston rings when made in tub-casting have shown good machining and wearing properties when made to the following analysis:

Element	Per Cent
Silicon	1.40—1.60
Manganese	0.50—0.60
Phosphorus	0.30—0.50
Sulphur	0.10—0.12
Total Carbon	3.00—3.20
Nickel	1.00—1.25
Chromium	0.20—0.30

Thin wall pistons show good machinability, toughness and wearing properties with additions of 1.00 to 1.25 per cent nickel. Large size pistons with heavier walls and Knight engine sleeves have shown more uniform machining properties and 25 per cent less wear with additions of 0.75 to 1.00 per cent nickel in combination with 0.2 to 0.4 per cent chromium, depending on the section and hardness desired. This application also extends to automobile and steam cylinders, ammonia cylinders and other castings requiring a strong dense fine grained iron. The strength and wearing properties of large boiler formers have been found to be greatly improved with 0.75 to 1.00 per cent nickel with 0.3 to 0.4 per cent chromium additions.

Each problem with its individual casting conditions and iron analysis may require some experimentation to secure the best results. The Cadillac Company has found that additions of 1.75 to 2.00 per cent nickel to their iron result in a fine grain iron, free from sponginess and water leaks and hard spots, although the hardness is increased 30 to 40 points Brinell on their cylinder walls. The matrix is found to be mostly sorbitic in its structure. This iron machines as readily as the iron of lower hardness and the resistance to wear is improved approximately 50 per cent.

The improved machinability of hard cast iron containing nickel was discussed earlier in the paper. This characteristic has resulted in a number of commercial applications which might be mentioned. The practice of several companies who are making

cams of cast iron has been brought to our attention. It is necessary to have these cams of a high Brinell hardness in order to secure wearing properties and prevent them from hammering out under load. It is also necessary to machine these cams so that the foundryman is left with a very narrow range to work in. If the silicon or total carbon becomes slightly too low the cams will chill on the edges, making them impossible to machine. If they vary in the other direction, the cams are too soft and will pound and wear out quickly. By using an iron 20 to 30 points lower in silicon than could normally be used, with the addition of 3 per cent nickel, the average hardness of the cams is increased by 30 to 40 points Brinell; the chilling of the iron and cementite hard spots are entirely eliminated, resulting in an iron of uniform machining properties.

Free cementite particles are apparently not securely imbedded in the iron and those on the surface are easily dislodged causing the surface to pit and the dislodged particle acts as an abrasive. As a result a nickel-iron without free cementite will polish and wear smooth while the iron with the cement particles will wear rough. These nickel-iron cams have shown considerable increase in life over the plain iron, in one case an increase of from 3 to 4 times was reported. A somewhat similar application is found in cast iron gears. The addition of alloy is governed by the size of the gear and analysis of the iron used. One company reports that they have added between 5 and 6 per cent nickel, getting a gear with high hardness which could be machined without much difficulty.

In the production of castings with considerable variation in section nickel has proved useful. One case in mind is that of a coupling, the body and hub of which had sections between 1¼ and 1½ inches while a flange around the circumference tapered to a ¼ inch section. It was found that if an iron with sufficient silicon was used so the flange could be machined the body of the casting would show shrink holes. To overcome this the silicon was lowered and from 1½ to 3 per cent of nickel was added, depending on the size of the coupling. This produced a sound casting free from shrinkage; they showed increased strength and the flanges could be machined without difficulty.

The fact that nickel will prevent chill in iron makes its use valuable for castings made with inserts of steel or other metals. Nickel cast iron has proven valuable as a filler-metal for gas or electric welding of cast iron. The nickel is not burned out in the welding operation as is carbon and silicon, resulting in a weld free from white iron and machinable. The addition of nickel to iron used for valve heads has resulted in a more uniform and dependable weld to the steel stem.

The increased compressive and shearing strength of nickel or nickel-chrome cast iron has found application by one company in increasing the shearing properties of its differential spiders.

The use of nickel and chromium has been found essential in a patented mixture. This material shows remarkable toughness and wearing properties when used in rolls, guides, grinding mills, die blocks and similar applications. It is also used in places where resistance to heat and oxidation is essential, as in pipe balls, melting pots and goosenecks for die casting machines. For pipe balls the use of 1.50 per cent nickel and 0.75 per cent chromium has proven advantageous.

The possibilities of the martensitic and austenitic irons are just being touched upon. A trial is being made on a large dredging pump containing low silicon and carbon with 9 per cent of nickel. It shows a high hardness and at the last reports the pump was wearing better than when made of manganese-steel. There are possibilities in its use for resistance to corrosion and oxidation.

The austenitic or non-magnetic iron shows large possibilities in connection with the construction of more efficient motor and generator units and as a substitute for brass castings. The iron is machinable, and its non-magnetic properties with high electrical resistance reduces the loss from stray eddy currents, increasing the efficiency of the machine.

The addition of nickel and chromium to cast iron is not advocated as a panacea for a foundryman's troubles, but with a thorough understanding of their effects under various conditions there are many difficult problems which yield to solution by their scientific application.

XVI. Summary

The results are given of a study of the effects of nickel and chromium additions on the properties of grey cast iron of principally three different grades carrying 1.40, 2.00 and 2.70 per cent silicon together with low sulphur and phosphorus. The nickel content was varied up to 5 per cent, the chromium content to 1 per cent, and the two alloy additions were made both singly and in various combinations.

This investigation has yielded results substantially corroborating the principal ones of previous investigations, as well as giving some explanation, it is believed, of some inconsistencies in the latter. Some of the present commercial applications of nickel and chromium bearing cast iron are described and suggestions made for further development of the use of these two alloys.

Some of the principal conclusions regarding the effects of nickel and of nickel chromium on the properties of grey cast iron based upon this work as well as upon the results of previous work follow:

Effect on Carbon and Graphite

Below about 4 per cent, nickel practically does not affect total carbon; at 5 per cent it begins to decrease it slightly as was found originally by Guillet.

Nickel accelerates graphite formation and carbide decomposition and therefore exercises a marked influence in reducing combined carbon to about 0.8 per cent, the eutectoid ratio, but acts only mildly, apparently, to reduce it below this value. This effect of nickel is roughly proportional to the amount of the nickel addition and is most prominent where the nickel content is 1 per cent or over.

Effect on Chill

Due to the active influence of nickel in breaking down carbides, the hard constituent of white iron, it is very effective in reducing chill and preventing the formation of white or mottled iron or hard spots, particularly in thin sections, at edges, corners, etc. This effect is quite positive with 1 per cent nickel or more and is

generally found with smaller amounts as well, down to about .25 per cent.

Chromium additions always tend to increase chill and combined carbon, and the iron with increasing additions tends to become white, mottled, hard and brittle, particularly at edges or corners. The presence of nickel restrains this effect of chromium, except that, curiously enough, small additions of nickel (.25 per cent or less) appear actually to intensify the chilling effect of small amounts of chromium.

The reduction of chill is one of the most useful functions of nickel in iron, since it serves to eliminate hard spots in castings of thin or variable section and thus to render them tougher, less fragile and more readily machinable.

Effect on Fracture

Apart from their effect on chill, nickel and chromium, alone or in combination, both serve to refine the grain of grey iron and this effect is obtained with relatively small amounts; viz., 0.15 to 3.0 per cent. With larger additions of nickel, 5 to 10 per cent, the grain is again coarsened and made more open.

Effect on Structure

Nickel encourages the formation of a cellular pattern, during solidification, within which graphite, ferrite and pearlite or sorbite are finely divided. Chromium assists in the development of this structure if the silicon is high. Excessive amounts of chromium (over ½ per cent) produce a second and coarser network of residual cementite superposed on the first. This cementite network will promote brittleness and may develop machining difficulties or accelerate wear. Nickel in the proper ratio to chromium, from 3 nickel to 1 chromium in low silicon iron to 3 nickel to 2 chromium in high silicon iron, serves to destroy the cementite network in either plain or chromium-rich irons and improve their structure as well as add desirable properties such as greater toughness, a solid solution hardness, improved strength, uniform machinability and greater wear.

Effect on Hardness

Chromium additions, of course, always increase the hardness of grey iron by causing it to become white or mottled or at least to increase its combined carbon. Decrease of silicon or total carbon content or increase of sulphur content will accomplish a similar change.

Nickel additions from .25 to 5 per cent also produce a substantial hardness increase in grey iron ranging from 10 to 100 points Brinell depending on section and silicon content of the casting.

The increase of hardness by nickel is of a totally different nature, however, than that obtained by addition of chromium or by variation of silicon, carbon or sulphur content. The iron is not thereby chilled nor is its combined carbon increased (usually with consequent machining difficulties), but that portion of the iron already combined with carbon (the pearlite) is rendered naturally and uniformly harder sorbite.

This is the reason why iron can be hardened with nickel additions and yet be as readily machined as in the softer condition.

The hardening effect of nickel is somewhat dependent, naturally, on the amounts of combined carbon in the casting and the most favorable results are usually obtained when this amount is not too low, preferably not below about 0.50 per cent.

Effect on Machinability

The machinability of grey iron depends primarily on its freedom from excess carbide, chilled or hard spots. Since nickel acts to eliminate these carbide areas it definitely improves machinability of iron subject to them. One per cent, and often less, of nickel is usually effective, depending upon the section, the silicon and carbon content and the amount of chromium also present.

Effect on Strength

Corresponding to the effects of nickel and chromium in refining the grain and in increasing the hardness of iron are similar effects of these alloys in increasing the strength—compressive, ten-

sile and transverse—the increases amounting to from 10 to 50 per cent.

The development of increased strength requires different amounts and even ratios of the two alloys for different compositions of iron and for different sections of castings. This is illustrated by Table 29 giving arbitration bar results on two different grades of iron.

Table 29

			Iron with 1.40 percent Silicon		Iron with 2.70 per cent Silicon	
Nickel Per Cent	Chromium Per Cent	Combined Carbon Per Cent	Transverse Strength Pounds	Deflection In Inches	Transverse Strength Pounds	Deflection In Inches
0	0	.72	3390	.132		
1.23	.10	.62	4510	.142		
1.10	.51	.80	4770	.142		
0	0	.44			2930	.128
.67	0	.44			3170	.138
.85	.59	.64			3980	.110

The action of nickel alone in increasing strength is dependent upon the presence of a reasonable amount of combined carbon, preferably as high as possible up to about .80 per cent, the eutectoid ratio, and not lower certainly than .50 per cent if substantial increases are sought. Nickel, as shown above, does not itself increase combined carbon and in castings carrying small amounts of combined carbon produces only small strength increases.

Therefore, in iron compositions which, by reason of high silicon or total carbon content, usually show a low combined carbon and less than the limits cited, some other means should be taken at the same time to raise this combined carbon.

An excellent means is the simultaneous addition of chromium. This is one reason that for many compositions of iron, nickel and chromium additions together will produce strength results superior to either of these alone. In this case the two elements function differently but in a supplementary manner.

Another method is the simultaneous reduction of silicon content, allowing the nickel to substitute for silicon in eliminating excess carbide. By this method cheaper irons or scrap may often be used partly offsetting the cost of the nickel.

Generally speaking, in order to secure substantial strength increase on arbitration bars the following additions are suggested:

For:

1.50 per cent Silicon-iron	Nickel .75—1.00 Cr. 0. —.25
2.00 per cent Silicon-iron	Nickel .75—1.00 Cr. .20—.40
2.60 per cent Silicon-iron	Nickel .75—1.00 Cr. .40—.50

The amounts of chromium here shown may be decreased for thinner sections.

Effect on Toughness

Nickel definitely improves the toughness of iron as measured by transverse deflection or other methods. The improvement is most prominent with higher nickel additions, from 3 to 5 per cent, and in thinner sections. Thus increases in deflection of 100 per cent and consequently in toughness can be obtained in ⅛ inch to ¼ inch sections by the addition of 3 to 5 per cent nickel.

This is of course partly due to the powerful action of nickel in eliminating excess carbides or hard and mottled corners and edges.

Even in iron (particularly in thin sections), which without the nickel is usually gray and free from chill, the addition of nickel further increases deflection and toughness. No explanation is yet available for this very definite effect.

In cases in which chromium has also been added to further improve strength, the nickel will serve also to improve the deflection or toughness which is often impaired by the presence of the chromium.

Effect on Shrinkage and Porosity

"Shrinkage" in solidification leading to internal porosity is not increased by the presence of nickel (below 5 per cent), but in the higher silicon grey irons which suffer from "shrinkage," suitable additions of nickel or nickel and chromium will reduce and may actually eliminate it.

Effect on Pattern Shrinkage or Contraction

Nickel and chromium additions up to 5 per cent and 1 per cent respectively exercise no effect on contraction of grey iron and usual pattern allowances are quite sufficient.

Effect on Fluidity

The "fluidity" of grey cast iron is not changed by the presence of nickel up to 5 per cent or of chromium up to .50 per cent, or by combination of the two within these limits.

On the other hand these tests have demonstrated the substantial effect of a slight decrease in total carbon or of a temperature lowering by as little as 100 degrees Fahr., in increasing the sluggishness of the iron whether or not it contains alloys.

Table 30

Article	Alloy	Reason for Adding Alloy
Thin Section Resistance Grids	5 per cent Nickel	To improve toughness
Thin Section Piston Rings	1-3 per cent Nickel	To improve toughness, machinability and resistance to wear
Pistons	¾-1½ per cent Ni.	To improve machinability and resistance to wear
Automobile Cylinders and Sleeves	Ni. 2 per cent Ni. 1.0 per cent Cr. 0.3 per cent	To improve density and resistance to wear
Cams	3 per cent Nickel	To secure maximum hardness still machinable
Rolls	1.50 per cent Ni. .75 per cent Cr.	To secure strength, toughness
Pipe-balls	1.50 per cent Ni. .75 per cent Cr.	To secure resistance to scaling at high temperatures
Forming Dies	1.00 per cent Ni. .40 per cent Cr.	To secure strength and toughness

Commercial Uses of Nickel and Nickel-Chromium Cast Iron

Table 30 lists some of the present typical commercial uses of iron alloyed with nickel or nickel chromium.

To summarize, suitable nickel and nickel-chromium additions to cast iron may be made to serve the following purposes:

To:

Increase transverse, tensile and compressive strength in all sections.

Increase toughness and decrease fragility, particularly in thinner sections.

Eliminate hard spots and to improve machinability particularly in thinner sections.

Increase hardness without impairing machinability.

Equalize hardness in sections of different dimensions.

Increase resistance to wear of machined or machinable surfaces.

Secure maximum hardness, uniform and machinable.

Reduce and regulate chill.

Secure fine-grain dense castings or surface (i. e. for polishing).

Secure resistance to oxidation and scaling at high temperatures.

Secure resistance to corrosion.

Reduce shrinkage and porosity in certain cases.

Cast Iron with Higher Alloy Content

As the nickel content of cast iron is increased to 5 to 12 per cent a series of alloyed irons may be produced which are martensitic and quite hard, particularly if chromium is also present. Thus an iron carrying 4.70 per cent Ni., .70 per cent Cr. and 3 per cent carbon showed a Brinell hardness of 578 on the 1¼ inch section.

As the nickel is increased beyond 15 per cent the hardness again drops and the iron is austenitic, but generally quite tough and flexible; it becomes also quite resistant to corrosion.

It is believed that for many special purposes the unusual properties of these higher alloy irons will prove valuable.

In conclusion, the authors must acknowledge the constant assistance of Dr. P. D. Merica, director of research, in the guidance of the work, and the help of Messrs. E. J. Bothwell and E. S. Wheeler with the extensive program of tests.

WRITTEN DISCUSSION

W. J. MERTON,* East Pittsburgh, Pa.

The authors present a very interesting paper on the influence of nickel on the physical characteristics of gray iron, which certainly covers a very large amount of valuable experimental work. The authors are to be congratulated for having been able to show the practical foundryman that nickel has a decidedly beneficial influence upon the structural condition of the gray iron casting if judiciously added and their work is of such extensive and voluminous character that little can be added. However, I wish to collaborate to some degree by considering another gray iron series, "The Non-Magnetic type," in which manganese and nickel are used as alloying elements for the obtaining of the non-magnetic and other electrical and physical characteristics desirable in electrical mechanism and machinery. Nickel in these irons apparently is added for a dual purpose, one of which is the promotion of precipitation of graphite thereby modifying the partly neutralizing action of manganese of retaining combined carbon (Fe_3C) and second to preserve the austenitic structural condition of the iron-nickel solid solution. These non-magnetic manganese nickel alloy gray irons are largely used abroad in very large electrical power plant machinery for end bells of the rotating field and for end castings of the stator.

A typical analysis of such iron is as follows:

Element	Per cent
Total Carbon	3.00
Manganese	5 to 7
Nickel	9 to 11
Silicon	1.25 to 1.50
Phosphorus	.40
Sulphur	.04
Aluminum	.75 to 1.00

The following are the characteristics of this iron:

A standard 1⅛ inch diameter transverse test bar gave on

*Materials and Process Eng. Dept., Westinghouse Electric and Mfg. Cc

12 inches supports a deflection of .15 of an inch and a breaking load of 2,900 pounds.

A tensile test gave an ultimate tensile strength of 21,000 pounds per square inch.

Electrical resistance 890 ohms. per circ. mil foot } at 28 degrees Cent.
Electrical conductivity 1.2 per cent

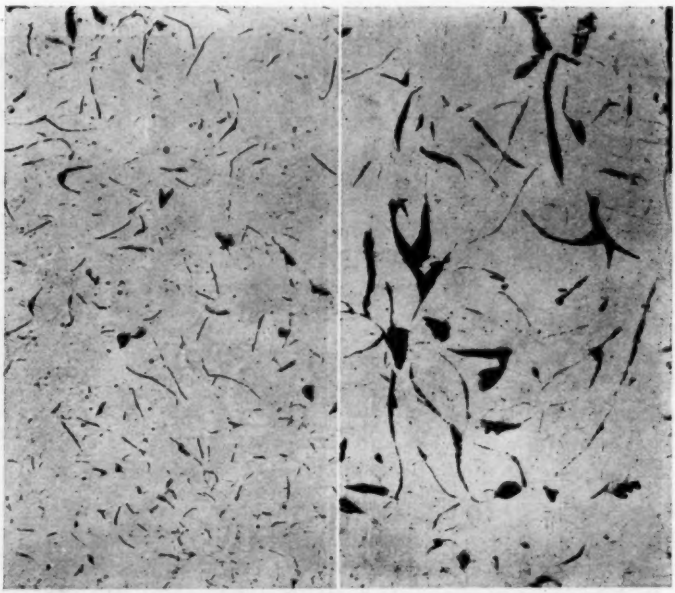

FIG. 1 FIG. 2

FIG. 1.—UNETCHED ALLOYED IRON
FIG. 2.—UNETCHED ORDINARY GRAY IRON

Observation made in the foundry showed that the iron did cast slightly more sluggish than ordinary cast iron. The molds, however, were well filled out and of perfect surface conditions. The castings machined well and the machined surfaces presented an appearance of a finished tooled steel casting surface. A photo-micrographical representation of the structure of such alloy irons

is given in Figs. 1 and 3, and as compared with section of ordinary gray iron Figs. 2 and 4 show a well-distributed and low percentage of graphite and a practical absence of large graphite flake segregation.

The above remarks have been prompted by a desire to show that the utility of nickel in a gray iron foundry is even greater than indicated by the authors of the original paper and it is hoped

FIG. 3 FIG. 4

FIG. 3.—ETCHED ALLOYED IRON
FIG. 4—ETCHED ORDINARY GRAY IRON

that a general appreciation of this fact is realized by giving proper publicity to such experimental results to men engaged in gray iron founding practice.

JAMES AITKEN,* Waterbury, Conn.

In reading this paper, the first thing that was apparent is the immense amount of careful study and extensive experimental work that was carried on in order to prepare the paper. The authors are to be congratulated on presenting such a masterpiece of work, and I am sure that the foundryman who is interested in producing a finer grade of cast iron will be amply repaid for any time he may give in a careful study of this paper.

The outstanding features of the article are the facts that the addition of nickel of 1 per cent or more to cast iron has a marked influence on reducing the chill; that chromium is a hardener and strengthener in iron in all proportions; that the addition of nickel in practically all cases is a strengthener of iron; that chromium has a similar property, and that the combination of nickel and chromium has a greater effect than either one separately. It is to be noted that nickel, while it increases the Brinell hardness of cast iron, does not increase the difficulty of machining.

Plain irons that were practically impossible to machine, machined quite freely after the addition of nickel; that chromium, on the other hand, when used alone creates a hardness that does increase the difficulty of machining. In addition to these properties, the addition of nickel and chromium gives a uniform hardness throughout a casting of different sections.

One point in particular that is well covered in the paper is the fact that the authors used as their base melt an iron made from 100 per cent pig iron, melted in a reverberatory furnace. The explanation of this as given in the paper is quite satisfactory and one can readily understand that in carrying on a scientific investigation it is essential to exclude any of the elements that would tend to complicate the findings.

However, in actual practice very few castings are made of 100 per cent pig iron, and further, a very large percentage of all castings are made from iron that is melted in the cupola. This gives variable conditions which are hard to control, particularly

*Manufacturers Foundry Co.

in regard to the sulphur content, and in actual practice this varying sulphur content will make it a little more difficult to get the desired result. While the paper shows the trend, it will be necessary for each producer of castings to experiment in his own plant with his own conditions before he will get the result for which he is aiming.

The writer has carried on some experiments with the use of nickel and chromium in cast iron. The results obtained by the writer are in substantial agreement with those of the authors of this paper.

The condition that was sought was uniformity of hardness and increased wearing qualities in a casting of varying section. This result was obtained after considerable experimental work by the use of an iron of approximately 2.50 per cent silicon, total carbon of 3.30 per cent, with the addition of .20 per cent of nickel and .3 per cent of chromium. The additions were made by means of nickel F shot and 65 per cent powdered ferro-chromium, no difficulty being encountered except in cases where the attempt was made to use ferro-chromium in larger pieces. When this was done it was found that some of the ferro-chromium did not melt and was found on the machined surface of the casting, giving a very hard spot.

The exact ratio of increase in wear has not yet been determined. That there is a substantial increase, however, is evident.

The experiments made by the writer were naturally very crude, and detailed information such as supplied by the authors of this paper was not available, so that the writer is extremely thankful that he now has such carefully compiled information as a guide for further experiments along this line.

JAMES P. FORAKER, Chicago Crucible Co., Chicago, Ill.

The paper on the effect of alloys, chromium and nickel, in cast iron by Messrs. Wickenden and Vanick is a most illustrious one and deserves the greatest praise from those interested in perfecting cast irons. It is almost impossible to cover the various

phases of this work with a direct comment applicable to the result in the use of alloys. There are so many uncertainties in cast iron which cause sporadic effects that the weaknesses in some of the physical qualities produced in the tests where alloys had been introduced cannot be directly attributed to the alloys. The conclusion which may be drawn from the tabulated results, however, shows that an improved cast iron is the outcome of the introduction of such alloys as nickel and chromium.

It has been our experience that nickel is a softener and toughener of cast irons while chromium is a hardener and strengthener when used separately. When these alloys are used in combination with each other they then offset the pronounced hardening or softening tendency and leave an iron which is strong and tough with excellent machineable qualities.

Our interest has centered not only on the effect of alloys on cast iron but also on the method of addition of alloys. We have found the ladle additions are more or less unsatisfactory due to the melting temperatures of the alloys and their power of absorption in cast iron. By ladle addition, we have had results which vary from fifty per cent recovery to ninety-five per cent of the alloy added. These spasmodic results are due to the temperature at which the alloy is added and the method employed. Further, by microscopic and chemical examination of various tests taken from the same ladle where alloy additions had been made, it has been evident to us that a perfect dissemination of the alloys is not obtained when these alloys have been added to the ladle.

To escape such results we have added the alloys in the cupola by using them with and without some kind of a binder or sort of a protecting tin sheet can.

The results by adding the alloys directly in the cupola charge were very unsatisfactory. The alloys seemed to migrate through the charges of iron and coke or they would become suspended in the slag to later come down in a subsequent charge. It was quite impossible to obtain consistent results. One time we would have twice the amount of the alloys expected in the test; and then again we would only have a trace of the alloys present. Such

un-uniformity could not be countenanced in perfecting a quality cast iron.

The use of tin can protectors was also investigated. These gave a better uniformity but the results were still inconsistent with the required positiveness of quality cast iron. This was due to the containers breaking open on the charging platform or to the sheet metal of the containers melting too high up in the cupola. Such conditions obviously expose the cast iron to un-uniform conditions.

Because of these uncertainties we concentrated our efforts on the selection of a binding material which would give a uniform result when the alloys were added in the cupola. After considerable effort and experiment we arrived at a binder of the following analysis:

Element	Per Cent
SiO_2	58.30
FeO	7.23
Al_2O_3	15.47
TiO_2	.72
Cr_2O_3	9.61
CaO	.60
MgO	.43
Co	.50
MnO	.05
SiO_2	.90
	4.10 Loss on ignition

This binder gave us the following uniform results:

Heat No.	Cr.	Ni.
6361	.12	.31
6362	.12	.30
6363	.13	.33
6364	Lost	.29
6365	.12	.30
6366	.11	.27

The analysis which went into the cupola was chromium 0.15 per cent and nickel 0.30 per cent. The foundryman performing this test for us and who was not interested in the method used,

stated: "This method of making the alloy addition is very effective as will be noticed by the chemical analysis."

In order to show the efficiency of this binder when used in the cupola to introduce alloys in cast iron, it was decided to experiment with the addition of ferro-silicon.

The first run was made on a mixture of 60 per cent pig iron and 40 per cent scrap adding to the charge 10 plugs of this binder

TABLE 1

PACKARD MOTOR CAR CO. TESTS

Chemical Composition	1 Chilled	2 Nickel	3 Charcoal	4 Standard	5 Soft	6 Chilled	7 Charcoal	8 Chromium Nickel
Per cent Combined Carbon	.14–.17	.16	.17	.16	.14	.14–.17	.17	.36
Per cent Total Carbon	3.16	3.10	3.13	3.20	3.28	3.16	3.13	2.93
Per cent Phosphorus	.122	.105	.133	.146	.220	.122	.133	.103
Per cent Sulphur	.097	.100	.077	.108	.099	.097	.077	.100
Per cent Silicon	2.40	2.63	2.35	2.77	2.58	2.40	2.35	2.58
Per cent Nickel	....	2.02	....	....	....	....	....	.86
Per cent Chromium	....	....	....	....	....	....	....	.32
PHYSICAL PROPERTIES								
Brinell Hardness	151	139	131	124	112	151	131	170
Rockwell Hardness B-Scale	82–83	75–77	69–71	68–72	64–66	82–83	69–71	85–86
Scleroscope Hardness	26–27	28–30	25–27	25–27	23–24	26–27	25–27	31–32
Transverse Breaking Strength in Pounds of 1 Inch Square Bar	....	2600	2350	2750	1900	....	2350	2700
Brinell of Test Bar	....	212	192	228	179	....	192	223

*Imperfect test bar.

The hardness, chemical composition, and micro-structure of each iron was taken from bores of the same cylinder block from which the sleeves for the experimental motor were taken. Bars for testing the transverse strength of each iron were cast at the time the blocks were poured.

carrying sufficient ferro-silicon to raise the silicon content 0.25 provided all of the ferro-silicon got into the metal without oxidation.

The second test was performed on the same type of charge with the silicon increased by 0.449 per cent if no oxidation took place. The charge going in was computed to be 1.62 silicon in

each case without considering the ferro-silicon addition. Therefore, the first test should come out at 1.87 and the second test

FIG. 1

FIG. 2

FIG. 1. CHILLED IRON—ETCHED WITH 5 PER CENT HNO_3—x100
REFERENCE COLUMN 1, TABLE 1
FIG. 2. TWO PER CENT NICKEL IRON—NOT ETCHED—x100
REFERENCE COLUMN 2, TABLE 1

at 2.07 silicon. The following is a result of the tests:

Cast	Silicon Per Cent 1st Test	Silicon Per Cent 2nd Test
1st Tap	1.80	2.127
2nd Tap	1.922	2.109
3rd Tap	1.912	1.978
Total	5.634	6.214
Average	1.878	2.071

It will be seen from these tests that 100 per cent recovery was obtained when an alloy, which oxidizes readily, was used.

With these gratifying results at hand we obtained permission from the Packard Motor Car Company to experiment with alloying of their cylinder iron to ascertain the effects of chrome and nickel in cast iron in production work. Table 1 gives the data of the experiment.

This table is indeed interesting because it illustrates the effect of nickel and nickel-chromium on cast iron. Column No. 4 is the regular grade of iron to which all of the other columns should be compared. Column No. 2 is a 2.00 per cent nickel iron. The

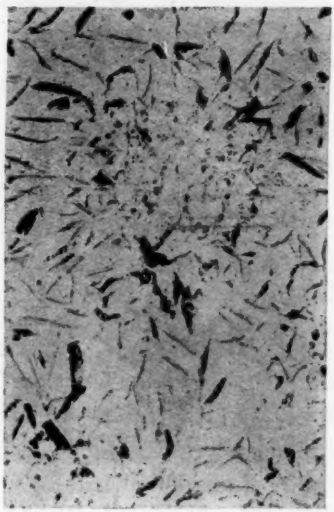

FIG. 3

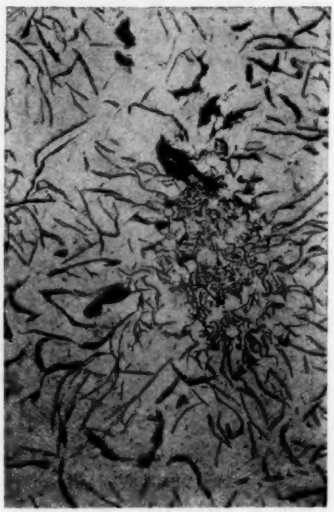

FIG. 4

FIG. 3. STANDARD PACKARD CYLINDER IRON—NOT ETCHED—x100
REFERENCE COLUMN 4, TABLE 1

FIG. 4. PACKARD SOFT IRON—ETCHED WITH 5 PER CENT HNO_3—x100
REFERENCE COLUMN 5, TABLE 1

nickel was added to the ladle. The increase in hardness shown in this column may be attributed to the lower carbon, lower silicon contents when compared to column No. 4. This analysis should give a stronger iron than No. 4, but the results were lower, thus proving that nickel is a toughener of cast iron. Column No. 8 is the chrome-nickel iron which was made by the introduction of the

alloys in the cupola through the means of the binder shown previously in this paper. The interesting feature of this column is shown by the increase in hardness with a very slight decrease in strength. Comparing columns 4, 2 and 8, it becomes evident that chromium and nickel additions together increase the hardness, toughness and strength. The machine tests showed that the cylinder cast from iron of test 8 machined as easily as cylinders from tests 2 and 4.

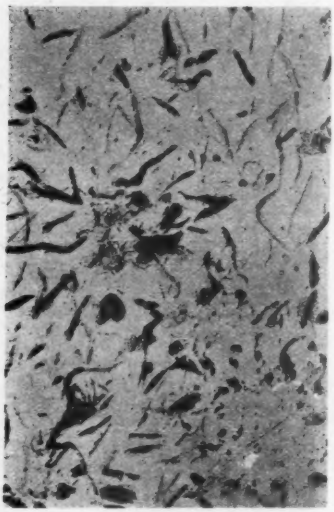

FIG. 5

FIG. 6

FIG. 5. CHARCOAL IRON—NOT ETCHED—x100. REFERENCE COLUMN 7, TABLE 1

FIG. 6. CHROME-NICKEL IRON—NOT ETCHED—x100. REFERENCE COLUMN 8, TABLE 1. IRON ALLOYED IN CUPOLA BY MEANS OF A BINDER

The recovery of alloys is also shown by the fact that the estimated analysis practically approximated the ultimate analysis.

The photo-micrographs of Figs. 1 to 6 show the carbon formations of the various tests. These pictures also show the effect that alloys have upon the geometry of the carbon growths.

In summing up the results of Messrs. Vanick and Wickenden, we believe that they have thrown the greatest light on the

subject of chrome-nickel in cast iron that has yet been published. Their work should aid the foundrymen in reaching a more satisfactory metal and to widen the application of gray iron.

D. H. Crosser, Chicago Crucible Co.

Commenting on the paper "Nickel and Nickel-Chromium in Cast Iron," by Thos. H. Wickenden and J. S. Vanick, my interest can be readily understood when it is remembered that I am engaged in commercializing alloys for cast iron and that I appreciate the dearth of authoritative information of commercial value up to the present time.

This contribution, evidencing as it does an immense amount of systematic investigating over an extensive range of tests that are applicable to commercial work, is gratefully received by all who are interested in better castings.

This paper in its summary of findings contributes greatly to the information on nickel and chromium as alloys for cast iron from a commercial standpoint, thus we are beginning to accumulate information on the subject and it is to be hoped that others will contribute from time to time on the effects of the various alloys so that we all may become familiar with the value of each of them in commercial castings.

Cast iron products in many instances have lost out to other branches of the metal industry, whereas, these displaced castings might well have been saved to the cast iron division had their quality been sufficiently developed to meet the demands that were required.

Failures are a frequent cause of cast iron being displaced by some other metal and while admittedly the substitute often has some quality or qualities far beyond the requirements of the occasion, it is evident that the cupola castings would not have been displaced had they been equal to the maximum demands required of them.

The cast iron founders have lost whole lines of casting work which today might still be made on their floors had they been "just good enough," to say nothing of a little better than required. If through the use of alloys in cast iron, qualities can be produced in castings that will lessen their displacement by other metal products, surely the foundrymen will be grateful for information on their use and the tedious and painstaking efforts of the various investigators of the subject will not have been in vain.

Evidently the authors have confined their experiments and comments described in this paper to the alloying of those castings that required machining, and in their summary under the paragraph "Effect on Hardness" apparently do not have in mind hardness as a desirable quality, but one rather to be avoided, when they state that "Chromium additions, of course, always increase the hardness of gray iron by causing it to become white, or mottled, or at least to increase its combined carbon. Decrease of silicon or total carbon content or increase of sulphur content will accomplish a similar result."

We believe that the authors will agree that if such a quality as resistance to abrasion or weight is the requirement of hardness that a chromium hardened iron will be superior and a different hard iron than that hardened by the decrease of silicon or increase of sulphur.

It might be well to illustrate this and the thought pointed out above—that lines of castings are lost to the founders—by referring to the grinding ball business. It is a well-known fact that the old ordinary white iron grinding ball is now almost entirely displaced by steel balls. The cost of mill balls is judged entirely by the tonnage they will grind, so that in many instances the forged ball which usually has an initial higher cost of 50 per cent or more than the cast iron ball was found to grind material cheaper per ton and so found adoption in many mills.

Fortunately for the foundryman it has been discovered that cast iron balls can be produced that will grind more material per dollar than forged balls. Recently there came to our attention the instance of a foundry that for years had had a daily production

of 5 to 6 tons of grinding balls. The business went to the forged ball maker. The user, who was a good customer on other castings, informed the foundryman that even at the price they were paying for the forged balls, their grinding was costing less. After several months of no business the foundryman approached his customer and explained that he believed that if he were allowed a nominal increase in price over what he had formerly received, he was of the opinion that he could make alloyed balls that would grind more material per dollar than the forged ball they were then using, with the outcome that he received a trial order for several carloads. The test was made and it was found that the cost of grinding material with the alloyed cast iron ball had an advantage of 46¼ per cent over the forged ball. The foundryman later received a standing order for the business at a better profit than he had been making previously. This test did not show that the alloyed cast iron ball resisted wearing quite as well as the forged ball, but the point to be considered is that the quality of the cast iron ball had been so improved that on a per ton grinding cost they showed a saving to the user of almost 47 per cent over the forged balls.

Undoubtedly, the alloyed cast iron balls here referred to are not the ultimate and it is to be hoped that some further research on weight and abrasion resisting iron may be soon available.

Throughout the discussion and summary of this paper little reference is made to the use of the additions of smaller percentages—under .50 per cent—of nickel and chromium and it might be inferred that while they do have an effect that they are of little commercial value in cast iron. Reference here is made to the circumstances surrounding the development of an alloyed iron for a particular purpose.

The concern undertaking this development has been long engaged in the manufacture of valve and tappet guides for internal combustion engines and enjoys a reputation for the high quality of its products. The machining specifications on these parts are very severe. It was felt desirable to improve, if possible, the wearing qualities of the iron in the guides and still main-

tain the high machining requirements of their shop which had been greatly hampered in previous attempts to get harder, yet, machinable iron in the ordinary ways.

Having in mind that the valve guide castings referred to weigh but a few ounces and may be described as small tubes, generally about 4 inches long and usually ¾ of an inch in diameter with walls from ⅛ to $\frac{3}{16}$ of an inch in thickness, it will be readily understood that great care must be taken in order to avoid producing hard castings, which would greatly hinder production in the machine shop.

After considerable experimentation, the base iron which had been used was found to be materially improved by the addition of alloys as indicated in the analysis shown on the right in Table I and was adopted as standard for this concern's product.

Table I

Regular Iron Analysis.		Regular Iron with Alloys Added Analysis.	
Si.	2.84	Si.	2.89
Mn.	.64	Mn.	.65
S.	.075	S.	.065
P.	.62	P.	.63
G. C.	2.80	G. C.	2.86
C. C.	.41	C. C.	.41
Ni.	None	Ni.	.45
Cr.	None	Cr.	.30
Ti.	None	Ti.	.001
Transverse	2536	Transverse	2856
Tensile	19588	Tensile	23330
Brinell	149	Brinell	197

This iron is alloyed in the cupola with an alloy formulated to maintain the .45 nickel and .30 chromium analysis. The formula also contained .15 Titanium C. F. Figs. 1 and 2 indicate the change in the structure of the iron caused by the addition of the alloys.

It will be noted that the Brinell hardness of 149 in the base metal has been raised to 197 in the alloyed iron, yet after rather elaborate tests it was determined that the machining quality had been increased by 14 per cent and the wearability increased to a very satisfactory point according to all the tests yet applied.

The case of the grinding balls referred to is an instance of the possibility of recovering business for the iron foundry by producing adequate qualities in them through the use of alloys which it is doubted could be obtained in any other way.

The case of the valve and tappet guides cited is an example of forward-looking manufacturers anticipating the possible re-

FIG. 1

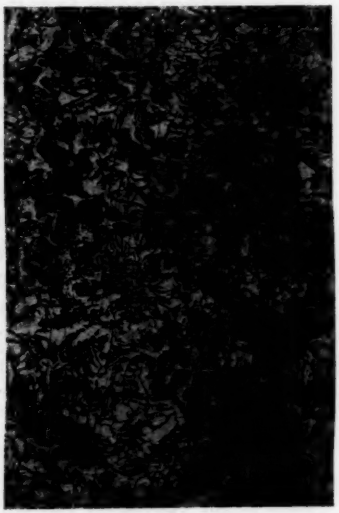

FIG. 2

FIG. 1—REGULAR IRON—MAGNIFIED 90 DIAMETERS.
FIG. 2—ALLOYED IRON—MAGNIFIED 90 DIAMETERS.

quirements of their customers and also putting themselves in a position to go after new business on a quality basis.

It has been pointed out in the paper under discussion that nickel and chromium have positive effects and that this is especially true of chromium alone and nickel and chromium in combination. Therefore, having determined the proper percentage of alloy, or alloys, which should be used for a particular line of castings, it is evidently imperative that considerable variations

in their alloy content should be avoided. Having referred to an instance where fairly large quantities of nickel and chromium are requisite and also to one where comparatively small percentages of alloys are effective, attention is naturally directed to the best method of using alloys in order that they may be of commercial value to the foundryman.

The writer has given much time during the past few years to this problem and he feels that he may be pardoned if he points out that there are difficulties in alloying either by ladle or spout additions or by the usual methods in the cupola.

Temperatures and dissemination are the usual stumbling blocks to the successful alloying of cast iron.

The introduction of small percentages of most alloys can be accomplished by ladle additions if great care and watchfulness is exercised, but little need be said of this haphazard method to the busy foundrymen who is engaged in the commercial production of alloyed castings in any considerable quantity. Attempts to introduce alloys by the spout or ladle method are well nigh futile, especially when thin castings are to be poured, or when the metal is low in silicon. The loss of heat is too great and it is also evident that the dissemination would be far from perfect. Melting the alloy before adding in the ladle helps of course, but in most cases this is impractical. Adding alloys in their original state in the cupola for the purpose of introducing small percentages is not feasible for obvious reasons and is rarely attempted.

Efforts are often made to affect additions of what are considered the larger amounts of alloys—1.5 per cent and upwards—by charging them free with the iron in the cupola, and this method through necessity is frequently adopted as practice.

It will be readily understood that crushed or lump alloys charged in the cupola by scattering them over the iron would accomplish dissemination were it not for the fact that they are in most instances subject to great loss through oxidation and that because of their size and disintegration they fall through the interstices in the shifting of the burden and accumulate in the bottom

of the crucible, there forming a rich alloy mixture which may all be contained in a single ladle if the cupola is drained by the tap. The subsequent tap would then be almost free of alloys.

Again, if the alloy is charged in units large enough to prevent their falling through the coke and iron two difficulties are often encountered. One of these is the lack of temperature sufficient to melt larger pieces of alloys having high melting points simultaneously with the iron in the charge. The other problem is that of diffusion made difficult through the inherent conditions in the cupola. If the temperature is sufficient to melt the alloy with the iron it will be found in pools in the crucible of the stack and must depend upon the movement created by tapping for the mixing action.

Often when the mixing is thought to be fairly well accomplished, when carefully checked, the iron will be found to show great variation of analyses in different parts of the heat. An instance illustrating this condition was discovered by a large firm in checking over about a week's run of castings to which 5 per cent of rather expensive alloy was to be introduced by cupola addition. This check showed a variance of alloy content indicating a lack of uniformity of analysis. Obviously, the purpose of the alloy additions would, in many instances, be defeated by the extreme variance in the analyses discovered by this check. It is believed that these variations could be practically eliminated by the use of process where the various alloys are especially prepared, their characteristic melting points and tendency to oxidation considered, and in a unit which accurately and conveniently introduces alloys singly or in combination in any prescribed percentages.

By the use of this practical method endorsed by leading foundrymen, metallurgists and the manufacturers of alloys and the increasing information on the value of alloys in cast iron it is hoped that the foundrymen will be enabled to develop their products so that they will meet the most rigid specifications.

W. E. DAY, JR.,* New Brunswick, N. J.

The authors through their paper have undoubtedly added considerable to the previous knowledge of this interesting and practical subject.

It would perhaps be well, however, to consider carefully the effect of higher sulphur than some .035 per cent on the necessary nickel-chromium ratio.

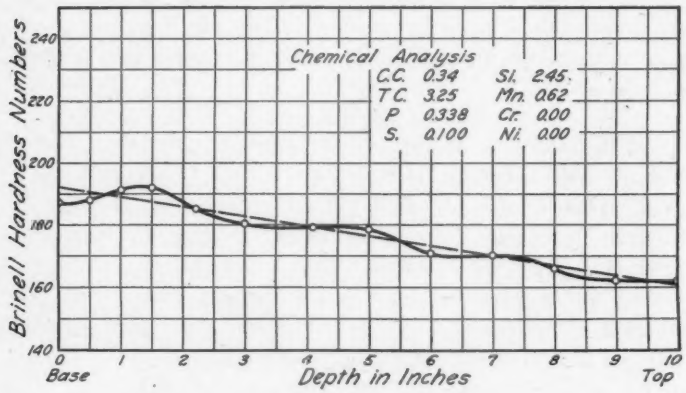

FIG. 1

On pages 371 and 372 reference is made to the uniformity in hardness existing in castings of varying sections due to the addition of nickel. To bring out further this fact the following might be mentioned illustrating the usefulness of nickel-chromium iron in procuring uniform hardness in castings whose sections, due to the form of the object, cool at vastly different rates.

Gasoline engine cylinders of the same pattern cast upright, using straight cupola iron, invariably show a decreasing hardness in wall from the base to the dome. This condition is obviously

*International Motor Co.

caused by the slow cooling of the upper end of cylinder. However, in cylinders cast from cupola iron to which the proper nickel-chromium addition has been made, little variation occurs.

Referring to curves of the appended charts, we see that the hardness, starting at the base rises slightly just inside the bore due to the lightness of section at this point in reference to the base. From this point on, the section is fairly constant to the dome. The cooling of the casting is, however, greatly retarded at the upper end because of the surrounding jacket. This gradual change

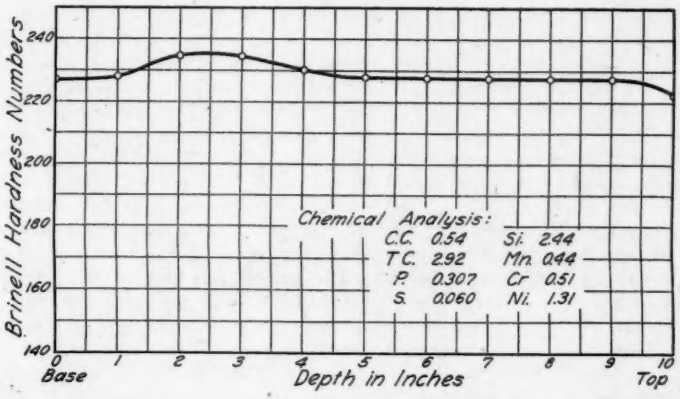

FIG. 2

in the rate of cooling from the base to the head causes a marked drop in hardness in bore of cylinder as shown in Fig. 1. The cylinder cast of nickel-chromium iron shows nearly uniform hardness to within a short distance of the head, Fig. 2.

It should be further noted that cylinders of type 2 machine as freely as those of type 1, in spite of the increased Brinell hardness due to the addition of nickel and chromium.

DISCUSSION

J. H. CRAWLEY: Have experiments have been conducted with lower total carbons than are shown in the tables?

T. H. WICKENDEN: Tests have been run at various plants with lower total carbon irons such as semi-steel mixtures and the effects really seem to be intensified with nickel and chromium, that is, the effect of nickel in reducing the chill is more effective, while at the same time the addition of chromium is more effective in increasing the chill. Excellent results have been secured, in some cases, by omitting the chromium, in others by using less chromium with the addition of nickel and adding a higher percentage of steel to the mixture.

P. KREULIN: I have looked over some of these tests where Mr. Wickenden added chromium and nickel in a synthetic way and found that the chromium would at all times increase the combined carbon and of course naturally increase the hardness. I happen to have some micrographs and analyses of a few automobile cylinders. This first picture is of a regular semi-steel, made at the Ferro Foundry. After using an iron which resulted in twice as much chromium as nickel, .09 nickel and .19 chromium, the combined carbon was reduced from .5 to .34. Of course those are figures that just happened to be. Some other analysis might have been combined carbon .60 and might have been reduced to .40. This second photo is of the valve seat of another casting. The combined carbon was .70, a semi-steel mixture without any chromium and nickel, and the other cylinder showed a resulting analysis of .10 nickel and .19 chrome, the combined carbon .37. The Brinnell hardness in this case was increased from 154 to 205. I would like to bring out to the foundrymen that with chromium and nickel added in a different way, it does not seem to have the effect that Mr. Wickenden referred to. This, of course, was made in cupolas and if the combined carbon at all times would be increased when chromium was higher than the nickel, I do not believe it would be very advisable to use any of that iron in automobile cylinders. I cannot state offhand just how many cylinders contained the mixtures I referred to; I think about 35 cylinders were finished with an analysis of that kind.

T. H. WICKENDEN: In comparing analyses it is always necessary to remember the other elements that affect the combined carbon. One is the amount of the total carbon present, another is the amount of silicon present, so that in making any study of the effect of nickel and chromium on the combined carbon, it is also necessary to remember the amount of these other elements. Otherwise you may be drawing incorrect conclusions.

DR. R. MOLDENKE: What does analysis of combined carbon and graphite mean? It does not mean anything, with all due respect to the

analyses, because unless you state where you get the sample from, it does not mean anything. The outside is one thing and the inside is different. If we get the average of the whole casting, it is different, but when you read these combined carbons and graphite analyses, you want to have the total behind the analyses.

I like to see a paper of this kind presented because I think it is in the right direction. I made quite a number of tests for the Bethlehem Steel Company on samples containing nickel and chromium and very elaborate results have been published. Fundamentally, it comes down after all to this, that your nickel softens and strengthens and your chrome hardens and toughens. If you had everything else equal, you would get those results that you have here, results which you can secure either by buying pig iron that contains nickel or by adding the nickel and improving the material. To go further, you have to remember that grey cast iron is essentially steel plus graphite; the combined carbon in the cast iron, whether little or much, is really a steel; the graphite is mechanically mixed and stuck between this steel and weakens it. You can see readily that if you can leave that graphite the same, anything you might put in that steel to make it stronger is a big advantage. On the other hand, if you change the graphite, if you increase it too much, all the money you put into increasing the steel part is lost; so it comes down to this, do you get uniformity in product? If you answer yes, good. The only question is, what does it cost? My only feeling is that if you put 5 per cent of nickel in cast iron the bank will break. If you put 1 or 2 per cent, it is all right.

These rarer or semi-rarer metals going through the blast furnace, reduced and put into the pig iron it is very much cheaper than the expensive electric way. I feel that the future will show us that the pig iron that contains nickel and chromium may be supplemented by additions to change the nickel and chrome relation. Then have this chrome re-diluted with iron so that you get a very weak alloy of chrome which can go through the cupola unchanged. When you add nickel and chrome direct to the ladle, you involve uncertainties of mixture, possibly, or at least you involve more cost, whereas, if you run it in the cupola, you must have it done so that it will not go to pieces before it gets through. Taken as a whole, I think this paper indicates good progress because the foundry needs to work in the direction of quality and the last thing I see in the direction of quality in the foundry game is the addition of these alloys to make alloy cast iron castings.

A. F. HILTON: Mr. Wickenden, have you had any experience in the production of this material and how much difficulty would we run into due to returned scrap?

T. H. WICKENDEN: It is being used in production all the way from a few tenths per cent of nickel or nickel and chromium to 5 per cent

of nickel additions, as in the grid, and on special iron even higher nickel and chromium additions. Of course it is best to segregate your scrap, sprues and gates and charge them in the mixture in which you are adding nickel in order to save the cost of the alloy The nickel is not oxidized, hence you get practically 100 per cent recovery.

G. W. GILDERMAN: Would a high combined carbon produced by the effect of manganese be treated the same as a high combined carbon produced by silicon, or would the manganese in any way affect the alloy?

T. H. WICKENDEN: That is a point I have not had an opportunity to work out and an answer would simply be a guess if I made it.

R. S. MACPHERRAN: If a casting runs high in manganese and you push the nickel high enough, you can still leave it machinable.

G. K. ELLIOTT: About fifteen years on and off, we have been discussing mixing nickel in cast iron, and this is the first really good paper I have read on the subject. I am very much interested in it, although I did not have a chance to see it previous to this meeting. There are one or two points that occur to me. One is that before you start mixing nickel rather indiscriminately, it would be well to study this paper, because undoubtedly there is something in here which will tell you how it will act upon your mixture. If you make a mistake and get too much nickel in the wrong iron, you are going to have a lot of trouble in the machine shop. I think it is very likely that these points are covered in the present paper. Another one is, Tuesday at the Round Table on Brass Foundry Practice, the fact was brought out that most all our brass and bronze scrap now has nickel in it, and I guess 75 per cent of the foundrymen present did not know that before; they were simply listening to this nickel discussion in a disinterested way and sympathizing with those who were wrestling with it, and somebody pointed out that they had the same problem. There is going to be a good deal of nickel in our American cast iron scrap in time. We may not want it there, but we may have it there willy-nilly, so it behooves us to post ourselves on the effect of small, possibly accidental quantities of nickel, and I may say that the same thing is true of chromium in our cast iron.

MR. CROMBLEY: It might be of interest if I mentioned a little experiment that we conducted in determining the value of nicked in cast iron. We took an iron with carbon of 2.82 per cent and 1 per cent silicon that had nickel added to the ladle. The finished analysis showed 1.50 per cent nickel. The transverse test was over 5100. It was machinable, easily machinable, and I thought it would pave the way to further research.

CHAIRMAN ROOT: What was the Brinnell on that?

MR. CROMBLEY: I do not remember, but it was easily machinable, with a 1 per cent silicon the bars of the same mixture and without the nickel broke at 2000 and it was unmachinable.

P. KREULIN: I would like to know whether that was furnace or cupola iron?

MR. CROMBLEY: I thought that someone would ask me that question, how did you get 2.82 per cent carbon? We found out that we could control our carbon; we have the converter process and add a little molten steel to our gray iron, which controlled our carbon, and we can get any carbon we desire.

J. E. FLETCHER: I have had some little experience with nickel and chromium alloy. A number of years ago my work lay with their manufacture. They were going through a series of experiments on the influence of nickel and chromium. At that time I had the research under my wing. It struck me that we might learn something from the addition of nickel and chromium to white cast iron. At that time we were using for all these armament alloys a base of Swedish iron, so that we started out with a very pure metal. We started with an alloy which was practically eutectic, practically pure carbon iron; that was a white iron. We started adding nickel until that ingot we cast became gray. That gave us our first point. We re-melted that alloy then started adding to it chromium until it turned the metal white. Those experiments were left aside for some years, but it was rather remarkable that the proportion between nickel and chromium in those experiments turned out to be practically the proportion that we had to use in armor piercing projectiles and in armor plate. It is somewhat strange, too, that this same proportion was the most useful proportion for toughening cast iron and it was almost the proportion that the reader of that paper has given to us this morning.

Another interesting experiment we tried at that time was having made a steel which was practically an armor plate. We started to cement the face of that armor plate and gradually picked up carbon until we reached the point at which the surface would take up no more carbon. Then, from a micrographic examination we found that the graphite was very marked. That brings me to the one point I wish to emphasize, and that Dr. Moldenke has also emphasized, and that is the carbon condition one has to look for in nickel and chromium influence. We found that it meant everything to us as to how we added nickel and chromium in manufacturing armor plate. Professor Howe showed us very emphatically that cast iron was still embrittled by graphite, so we see how necessary it is to look at these nickel chromium additions in the light of cast iron being steel embrittled by graphite. The very remarkable series of tests given this morning I think will enable all interested in a critical sense to get somewhere near the percentage of nickel and chromium that will be found best in cast iron.

There is a warning, however, to be given in getting homogeniety of structure; so much depends on the size of the casting that you are dealing with. Years ago I made propellors for ice breakers for the Russian

Service; they were steel castings containing practically 3 to 3.5 per cent nickel. Some were returned broken, although they contained only about 1.4 or 1.5 carbon. These broken castings were returned to the works and we examined them and found they were very high in graphite in the thick portion. Those are just hints that may be of service to those who are going to use nickel and chromium in cast iron. I should like to add that there seems to us in England quite a future for nickel chromium irons if they are made not haphazardly but along such lines as the author has given.

The Oxygen Content of Coke and Charcoal Cast Irons

By J. R. Eckman and Louis Jordan, U. S. Bureau of Standards, Washington, D. C., and W. E. Jominy, University of Michigan, Ann Arbor, Mich.

I—Introduction

A year ago a paper was presented before the American Foundrymen's association by W. E. Jominy comparing the mechanical properties of charcoal and coke pig irons and of the remelted cast irons from these two types of pig iron.[1] The data given in that paper showed that the average Brinell hardness, tensile strength, transverse strength, and deflection for cast iron test bars prepared by melting charcoal pig iron were all appreciably higher than for those of approximately the same chemical composition but prepared by melting coke pig irons. Results obtained with a second series of test bars cast from the remelted original bars showed that these differences in the mechanical properties, in favor of the charcoal irons, persisted after the remelting of the original castings.

Jominy also called attention to a difference in the size and form of the graphite in the strong and weak castings. The graphite of the coke irons in general was in the form of rather thick and long flakes or plates, while the graphite of the charcoal irons tended towards smaller and more rounded particles. It was regarded as logical that the thicker and longer graphite flakes in the coke irons should be held responsible for the weakness of those irons inasmuch as the longer flakes broke up the continuity of the metallic matrix to a greater degree than did the smaller and more rounded graphite particles of the charcoal irons.

*Published by Permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[1]W. E. Jominy, Characteristics that Chemical Analysis Fails to Disclose in Pig Irons and Castings, Trans. American Foundrymen's Assoc., *32*, Part I, pp. 476-95; 1924.

II—Johnson's Hypothesis Regarding Oxygen in Cast Iron

J. E. Johnson, Jr., concluded from his investigations on the influence of oxygen on the strength of cast iron[2] that under identical melting and casting conditions irons containing considerable amounts of oxygen were stronger than irons of practically the same chemical composition except for a lower oxygen content; that pig irons made at lower temperatures contained more oxygen and, therefore, charcoal pig irons, made normally at lower blast temperatures than coke pig irons, contained more oxygen and yielded stronger castings. He further stated that oxygen had this effect on the strength of cast iron through its influence on the form in which the graphite separated. The higher oxygen content of the charcoal irons was stated to be the cause of the more nodular form of graphite in those irons.

Jominy's comparison of coke and charcoal irons confirmed Johnson's statements of the tendency towards higher strength in charcoal irons, quite probably caused by the smaller, more nodular graphite. Jominy's work also tended to support Johnson's claims that the cause of these differences between strong and weak (charcoal and coke) irons should be sought in some as yet unrecognized difference in chemical composition since the differences in structure and strength persisted on remelting and casting under parallel conditions.

Analyses for oxygen made by Johnson by the Ledebur method indicated higher oxygen content in the stronger pig iron of each of the three pairs of strong and weak irons listed in his report. In as much as this was the only difference found in the chemical composition Johnson argued that it was the cause of the difference in physical properties and that this difference in oxygen content persisted in the remelted cast irons since the same differences in physical properties remained.

The Ledebur method for oxygen used by Johnson is of limited application and could not have given accurate results on a high carbon material such as pig iron, when only the oxygen of

[2]J. E. Johnson, Jr., The Influence on the Quality of Cast Iron Exerted by Oxygen, Nitrogen, and Some Other Elements, Trans. Am. Inst. Min. Eng. *50*, p. 314; 1914. Also U. S. Patents 1,106,817; 1,150,201; and 1,231,259.

the water in the gases leaving the furnace was determined.[3] The error on this account would result in values for oxygen lower than the true values since a portion of the oxides in the sample would be reduced by the carbon in the metal.

The higher values for oxygen reported by Johnson, however, are quite considerably in excess of the amounts of oxygen usually found in pig irons or cast irons by the method, lately developed at the Bureau of Standards, for determining oxygen by fusion in vacuum.[4]

Table 1

JOHNSON'S VALUES FOR OXYGEN IN STRONG AND WEAK PIG IRONS

Type of Iron	Trans. Strength Pounds	Total Carbon Per Cent	Graph. C Per Cent	Comb. C Per Cent	Si Per Cent	Mn Per Cent	P Per Cent	S Per Cent	O Per Cent
Strong.....	3,200	4.00	3.22	0.78	1.90	0.62	0.139	0.017	0.027
Weak.....	2,700	4.09	3.43	.66	1.88	.70	.112	.020	.009
Strong.....	3,450	4.00	3.05	.95	1.00	.46			.038
Weak.....	2,650	4.05	3.15	.90	1.00	.50			.009
Strong.....	3,850	4.10	3.50	.60	.70	.60	.128	.035	.065
Weak.....	2,500	4.49	3.60	.89	.72	.59	.108	.024	.009

III—Oberhoffer's Work on Oxygen in Cast Iron

Following Johnson's first suggestion that the presence of oxygen in cast iron was an advantage, the literature records varying opinions on the point and some data in support of Johnson's claims.[5]

In determinations of oxygen in cast iron made quite recently, Oberhoffer and his associates have obtained results which support Johnson's claims of the strengthening influence of oxygen.[6] In grey cast irons containing approximately 3.5 per cent total carbon and 1.7 to 1.8 per cent silicon, they found oxygen to vary from 0.046 to 0.198 per cent by weight. By plotting oxygen against

[3] J. R. Cain and L. Adler, Equilibrium Conditions in the System, Carbon, Iron Oxide, and Hydrogen in Relation to the Ledebur Method for Determining Oxygen in Steel. Sci. Papers, Bureau of Standards, No. 350; 1919.

[4] Louis Jordan and James R. Eckman, Gases in Metals II. The Determination of Oxygen and Hydrogen in metals by Fusion in Vacuum. Bureau of Standards Sci. Paper No. 514.

[5] J. A. Pickhard, The Oxygen Content of Iron and Steel, Iron and Steel Inst., Carnegie Scholar. Mem., *7*, pp. 68-82, 1916; W. L. Stork, Oxygen in Cast Iron and Its Application, Iron Age, *103*, pp. 1636-7, 1919, J. Shaw, Problems of the Foundry, Foundry, *49*, pp. 759-61, 1921.

[6] P. Oberhoffer, E. Piwowarsky, A. P. Schiessl and H. Stein. Ueber Gas- und Sauerstoffbestimmungen in Eisen insbesondere Gusseisen. Stahl und Eisen, *43*, pp. 113-116; 1924.

mechanical properties their average results for three series of irons indicate that with increasing oxygen the Brinell hardness, modulus of rupture, tensile strength, and shrinkage all increase, while the impact resistance and density decrease. Oberhoffer also points out the occurrence of smaller graphite flakes in the irons containing the larger amounts of oxygen.

Oberhoffer's values for oxygen in the cast irons he examined were obtained by a modified Ledebur method which should give more correct results than the method used by Johnson. Oberhoffer's values for oxygen are nevertheless higher than Johnson's and, consequently, far above the values obtained on any cast irons by the Bureau of Standards' vacuum fusion method.

IV—Methods for Determining Oxygen in Cast Iron

1. Ledebur Method

The original Ledebur method, as used in Johnson's work, determined the water formed by passing hydrogen over a sample of pig iron chips heated to 900 to 1000 degrees Cent. Cain and Adler have shown that such a procedure, in the case of ferrous materials containing combined carbon, would fail to recover all of the oxygen in the sample since a considerable proportion of the oxide would be reduced by carbon and would be present as CO or CO_2 in the gases leaving the furnace. More recently Oberhoffer[7] has called attention to the same difficulty. Johnson's results for oxygen in his pig irons, therefore, must be in error on this account.

Oberhoffer made provision for determining both CO and CO_2 in the gases leaving the furnace in the modified Ledebur method used in the research in which he confirmed Johnson's earlier work.

2. Bureau of Standards Vacuum Fusion Method.

The vacuum fusion method developed and in use at the Bureau of Standards for the determination of oxygen in iron and steel is more satisfactory than either of the preceding methods as applied to pig irons or cast iron. The reduction of the oxides in the iron is accomplished by means of carbon. The sample of iron, as a single piece of metal weighing about 30 grams, is very care-

[7]See footnote 6.

fully cleaned by grinding the surface and washing in alcohol and ether. It is then fused by high frequency induction heating in a gas-free graphite crucible placed within a closed-end silica tube and the H_2O, CO_2, CO and H_2 evolved from the sample are determined gravimetrically.[8] The sample is held molten for an hour or longer at 1450 to 1500 degrees Cent. under reduced pressure to allow the complete reduction of all oxides. It has been shown that under these conditions the oxides of iron, manganese, aluminum, silicon, titanium and zirconium, which may be present in an iron or steel, are completely reduced.

3. *Possible Errors in Oxygen Due to Preparation of Samples*

Both the original Ledebur method used by Johnson and Oberhoffer's modified method require the use of a finely divided sample of the pig iron or cast iron. Neither Johnson nor Oberhoffer state in detail how their samples were prepared or what precautions were taken to prevent surface oxidation of the fine iron chips. That surface oxidation may cause very serious error has been shown by many analyses made by the vacuum fusion method on chips and single-piece solid samples from the same material. For example, a steel which contained 0.02 per cent oxygen according to the vacuum fusion method using a solid sample, gave a value for oxygen of 0.04 per cent when the analysis was made on milled chips even though the chips had been cut under oil and then very carefully cleaned and dried. A second example, even more to the point in the present discussion of cast iron, was the case of two white irons made for malleabilizing. Samples of these hard irons were prepared by crushing under an air hammer in a tool-steel mortar. The crushed iron sample was separated into two portions, one of material passing a 20-mesh but not a 40-mesh screen, and the other of material passing a 40-mesh but not a 120-mesh screen. These two samples of each iron were run separately for oxygen by the vacuum fusion method as well as a solid sample of each iron. The results show that the values for oxygen obtained on the crushed samples gave no indication of the actual oxygen content of the iron.

The results in Table 2 for the coarse and fine crushed sam-

[8] The detailed description of this method is given in the reference cited in footnote 4.

ples are of the same order of magnitude as the values for oxygen reported by Johnson (0.01 to 0.07 per cent) and Oberhoffer (0.05 to 0.2 per cent). The vacuum fusion method, using solid samples with carefully ground and cleaned surfaces, thus far has given an oxygen content always lower than 0.02 per cent for cast irons of normal production.

V—Oxygen in Coke and Charcoal Cast Irons

In as much as the vacuum fusion method for oxygen appears to be more satisfactory than any of the previously used methods for determining oxygen in cast iron, analyses were made of some of the charcoal and coke cast irons investigated by Jominy.[1] The results of such analyses have failed to support the conclusion of Johnson and of Oberhoffer as to the strengthening effect of oxygen on the mechanical properties of grey cast iron.

Table 2

OXYGEN IN WHITE CAST IRONS
ERRORS DUE TO SURFACE OXIDATION OF CHIPS

Type of Sample	Oxygen, Per Cent by Weight	
	Iron I	Iron C-1
Solid piece	0.009	0.009
Coarse crushed (20-40 mesh)	.045	.051
Fine crushed (40-120 mesh)	.108	.124

All analyses were made in duplicate and on samples of one or two solid pieces of cast iron with carefully ground and cleaned surfaces. The numbering of the samples is the same as in the original paper by Jominy. An "X" preceding the sample number designates the first remelt of a pig iron, while "XX" denotes a remelt of the single X cast iron. In the tabulation of results, less than 0.001 per cent oxygen is reported as "Nil." The charcoal and coke irons are listed in Tables 3 and 4 in the order of decreasing tensile strengths. It is very evident that the stronger (charcoal) irons are not distinguished from the weaker (coke) irons by any higher content of oxygen. This is more readily seen in the left-hand portion of Fig. 1 where the oxygen contents of both types of iron are plotted against the tensile strength. Quite contrary to Johnson's and Oberhoffer's results, however, if one considers the charcoal and coke iron series separately, those irons of either type which show the higher strengths of their group are generally low in oxygen. None of the irons listed in Tables 3 and 4 have an

oxygen content nearly as high as the minimum value, 0.04 per cent, reported by Oberhoffer for his cast irons and the highest oxygen content of any iron in the present investigation, 0.014 per cent, is very nearly the same as the minimum value, 0.009 per cent, reported by Johnson and the content of his weak irons.

Table 3

GASES IN CHARCOAL CAST IRONS

Sample Number	Tensile Strength Pounds per Square Inch	Gases, Per Cent by Weight: Oxygen Det'ns.	Oxygen Average	Hydrogen Det'ns.	Hydrogen Average	Nitrogen Det'ns.	Nitrogen Average
X76	31,500	0.005 Nil Nil	0.002	0.0004 .0002 .0002	0.0003	....	.....
X75	30,400	Nil Nil	Nil	Nil Nil	Nil	0.001 .001	0.001
X60	29,800	Nil Nil	Nil	Nil .0001	<.0001	.001 .001	.001
X11	28,850	Nil Nil	Nil	Nil Nil	Nil	.001 .001	.001
X79	27,400	Nil Nil	Nil	Nil Nil	Nil	.001 .001	.001
X74	27,000	Nil .001	<.001	Nil Nil	Nil	.001 .001	.001
X 0	25,850	.004 .001 .006	.004	.0006 Nil .0005	.0004	.001 .001	.001
X69	25,200	.008 .006	.007	.0005 .0006	.0006	.002 .002	.002
X66	24,800	.010 .010	.010	.0008 .0009	.0009	.002 .003	.003
XX60	.....	.002 .005	.004	.0001 .0005	.0003	.001 .001	.001
XX74	.....	Nil Nil	Nil	Nil .0001	<.0001	....	.....
XX75	.....	Nil Nil Nil	Nil	.0014 Nil .0001	.0005	.001 .001	.001
Average			0.002		.0003		.001

VI—Hydrogen and Nitrogen in Coke and Charcoal Cast Irons

The hydrogen and nitrogen contents of the coke and charcoal irons are listed in Tables 3 and 4. Values for the hydrogen content of all samples were obtained in the course of the determination of oxygen by the vacuum fusion method. Less than 0.0001 per cent hydrogen is reported as "Nil." Values for nitrogen were

obtained by the Allen method for combined nitrogen.[9] Neither hydrogen nor nitrogen contents show any differences characteristic of the stronger or weaker irons.

VII—Supplementary Tests

When it became evident that the content of oxygen, nitrogen, or hydrogen did not serve to distinguish the strong and weak irons, two supplementary tests were made without, however, attempting any systematic examination along lines other than gas content. Combined carbon was determined in a number of representative

Table 4

GASES IN COKE CAST IRONS

Sample Number	Tensile Strength Pounds per Square Inch	Gases, Per Cent by Weight					
		Oxygen		Hydrogen		Nitrogen	
		Det'ns	Average	Det'ns.	Average	Det'ns.	Average
X 7	25,600	Nil Nil	Nil	Nil Nil	Nil	0.001 .001	.001
X 6	23,500	0.003 .003	0.003	0.0004 .0005	0.0005	.002 .002	.002
X37	21,600	.014 .014	.014	Nil Nil	Nil	.001 .001	.001
X 4	21,600	.002 .002	.002	.0002 .0001	.0002	.001 .001	.001
X 3	21,500	Nil Nil	Nil	.0003 .0003	.0003	.001 .001	.001
X23	21,000	.005 .006	.006	.0001 Nil	<.0001	.001 .001	.001
X36	17,100	.008 .009	.009	.0002 .0004	.0003	.001 .001	.001
XX37	.....	.003 .003	.003	Nil Nil	Nil	.001 .001	.001
Average			.005		.0002		.001

irons and spectrographic analyses were made on two coke and two charcoal irons. The first test was made in order to indicate whether the higher strength of charcoal irons should be attributed to a matrix which was stronger on account of the smaller, more rounded form of graphite, or on account of higher combined carbon. The spectrographic examination was made on the chance of detecting some less common metallic element present in one class

[9]The determinations of nitrogen were made by R. J. Kranauer of the Bureau of Standards using the Allen method as described in Bureau of Standards Scientific Paper No. 457.

of irons but not in the other and which had escaped determination in the usual analyses.

1. Combined Carbon

Determinations of combined carbon[10] were made on as many samples as were available of those charcoal and coke irons that were selected by Jominy in his paper[1] for comparison in pairs on

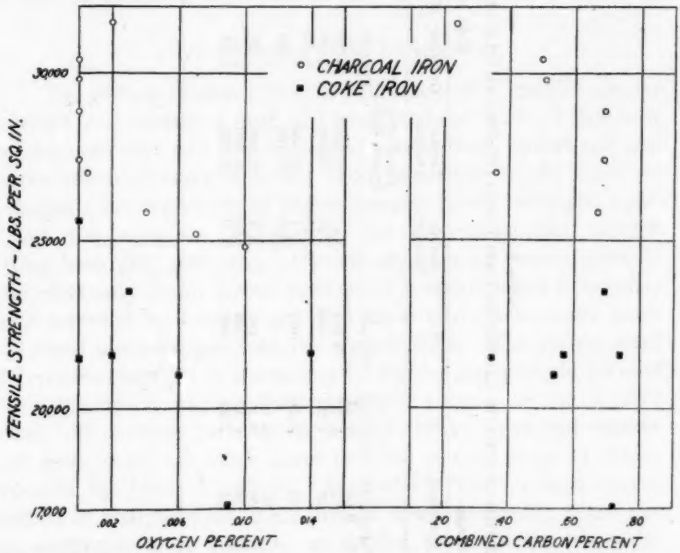

FIG. 1—RELATION OF TOTAL OXYGEN AND COMBINED CARBON TO TENSILE STRENGTH OF COKE AND CHARCOAL CAST IRONS.

the basis of similarity of chemical composition as judged by the silicon content. The results of these analyses are given in Table 5. It is evident that the combined carbon also fails to furnish any difference in chemical composition characteristic of the strong or weak irons. This is shown also in the right-hand portion of Fig. 1 where combined carbon is plotted against tensile strength.

[10]Analyses made by C. P. Larrabee of the Bureau of Standards.

Table 5

COMBINED AND GRAPHITIC CARBON IN CAST IRONS OF SIMILAR SILICON CONTENT

Charcoal Irons						Coke Irons					
Sample Number	Tensile Strength	Graphitic C	Combined C	Si	S	Sample Number	Tensile Strength	Graphitic C	Combined C	Si	S
	Pounds per Square Inch	Per cent	Per cent	Per cent	Per cent		Pounds per Square Inch	Per cent	Per cent	Per cent	Per cent
X11	28,850	3.42	0.69	1.27	.....						
X 0	25,850	3.29	.67	1.70	0.012	X6	23,500	3.22	0.69	1.70	0.015
X60	29,800	3.39	.51	1.90	.009	X37	21,600	3.09	.74	1.99	.033
						XX37	.....	3.18	.62	2.03	.....
X79	27,400	3.31	.69	2.04	.011	X 7	25,600	.....	.....	2.06	.016
						X36	17,100	3.00	.72	2.10	.....
XX75	.....	3.22	.60	2.11	.....						
X75	30,400	3.36	.50	2.15	.009	X 4	21,600	3.28	.57	2.11	.027
X74	27,000	3.43	.36	2.47	.009	X23	21,000	3.10	.54	2.44	.026
X76	31,500	3.54	.24	2.84	.009	X 3	21,500	3.21	.35	2.88	.020

2.—Spectrographic Analysis

The arc spectra of two charcoal and two coke irons (X 60 vs. X 37 and X 74 vs. X 23) of similar composition were compared in the attempt to detect the presence in either the coke or charcoal irons of any unusual metal characteristics of either type of iron. Titanium, vanadium, chromium, nickel, and copper were shown on the spectrograms. From visual estimates of the intensities of the spectral lines no differences in any of these elements were indicated as characteristic of either class of iron.[11]

VIII—Summary and Conclusions

The general tendency of charcoal cast iron to exhibit greater strength and contain a finer and more nodular form of graphitic carbon than coke cast iron of similar composition, melted and cast under identical conditions, has been attributed on the basis of Johnson's investigations to higher oxygen in the stronger irons. Oberhoffer supports Johnson in the contention that oxygen strengthens grey cast iron. Careful analyses of twelve charcoal and eight coke irons, whose mechanical properties had previously been reported by Jominy, failed to show that the stronger irons contained more oxygen than the weaker irons. The rather small differences observed in the results of the oxygen analyses pointed more towards a slightly higher oxygen content in the weaker irons. The values for oxygen in both the stronger and weaker cast irons were very much lower than the general range of values reported by Johnson and by Oberhoffer. The vacuum fusion method of analysis used in the present investigation for determining oxygen is more accurate, as applied to cast irons, than the methods employed in previous investigations. Determinations of hydrogen, combined nitrogen, graphitic and combined carbon, and spectrographic analyses for minor metallic constituents likewise failed to reveal any differences in chemical composition which were characteristic of the charcoal and coke cast irons.

[11]For this spectrographic examination we are indebted to W. F. Meggers of the Bureau of Standards.

DISCUSSION

CHAIRMAN A. B. ROOT, JR.: Gentlemen, I think we cannot but be impressed with the nature of the research work Dr. Eckman and his associates have been carrying on. It is an exceedingly interesting subject, a subject that requires the very greatest painstaking care and the most extreme accuracy.

DR. R. MOLDENKE: Would you kindly explain what adsorption means as against absorption?

Dr. ECKMAN: Let us consider the case of a gas taken up by solid particles. In adsorption the gas adheres to the surface of the solid, whereas in absorption the gas penetrates into the inner recesses of the solid. In our regular vacuum fusion method of determining oxygen, involving the use of a carefully cleaned solid sample, we seem to get a negligible adsorption effect. However, some milled samples of cast iron which were allowed to stand in dry air increased in oxygen content, due possibly to the adsorption of oxygen by the fine particles of graphite in the milled samples. It may be that when a charcoal iron is milled it produces more finely divided particles of graphite than does a coke iron. In such a case the charcoal iron millings would no doubt take up more oxygen than the coke iron millings. This has not yet been determined. If this theory should prove to be true, it would unfortunately not explain the greater strength of the charcoal iron, but it might explain why Johnson's and Oberhoffer's stronger irons showed higher oxygen content than their weaker irons.

DR. MOLDENKE: I was delighted to have your conclusions. They go to show that Johnson's were not verified and that the thing is practically in statu quo, and you can begin anew. It also shows, as brought out yesterday, that the chemical analysis of iron is by no means finished and oxygen is not the only thing. Hydrogen may be doing something that we do not yet know. I have been constantly opposed to Johnson all the time. We were good friends personally, but when it came to oxygen I always had to tell him this: "You claim you have harder iron and stronger iron when you have oxygen?" "Yes." "I grant you that, because the real thing is that when you get a stronger, harder iron of a given composition compared to one that is weaker, you have a quicker setting of that iron, the iron has no life and the foundryman says 'That ladle has to be poured right away or we will lose the casting.' You see, something happened in the iron, whether due to oxygen, hydrogen or nitrogen. I think it is dissolved iron oxide that has raised the freezing point, but I cannot prove it. I am waiting for your work at the Bureau of Standards, but I will call Johnson's attention to this. Granted that you have harder and stronger iron, the danger is that, if you do have oxygen in some form in the iron, your metal sets fast and when you have excessive gas or

excessive dissolved iron oxide in that iron, it unites with the carbon at the wrong minute and you get a little bubble under the core. Then when you shave off the surface you see the bubble in the form of a collection of pinholes. This is always a sign of a low bed in the cupola and an oxidized condition. Whether we can prove that, that is, I think, up to the U. S. Bureau of Standards and to the Bureau of Standards of Sweden and Germany and of other overseas countries, to get more correct methods. However, I am glad you have brought it down to the point where you have to begin at the beginning and go over again. I want to point out this: Johnson always claimed that his oxygenated iron, which is iron blown about two minutes in the converter and made into pig iron, was a wonderful strengthener, etc., etc. It was a strengthener and a hardener, because that iron set faster and gave more the relation of carbon and graphite, but I notice there is none of it any more, the oxygenated iron has disappeared completely out of use, so that those things do not live.

I. E. WAECHTER: I think the authors of this paper are to be congratulated for setting at rest the minds of so many of us. I do not take very great stock in the Johnson-Oberhoffer theory. We know from other metallurgical processes that gas in molten iron or gas in iron after it solidifies is not a very good thing. As a matter of fact, most good metallurgical practice provides for deoxidation and degasification. We do that by various means in the mold, or by the addition of special elements. In our gray iron foundry we are most particular, as far as the coke is concerned, to prevent the oxidation of iron. Thus the results which the authors have embodied in this paper are very gratifying, inasmuch as they show that oxygen, if anything, is a disadvantage or a bad thing to have in cast iron.

There is one thing, however, I must say in regard to the paper: they have not gone far enough. They have shown that oxygen is not a particular element which adds to the strengthening effect of the charcoal iron, but they have not explained what it is that causes the greater strength of charcoal iron over the coke iron. In going over Johnson's hypothesis, I note that the principal hypothesis is this: "pig iron made at lower temperatures contains more oxygen and, therefore, charcoal pig iron made normally at lower blast temperatures than coke pig iron contains more oxygen and yields stronger castings."[2] From the work I have done on cast iron and steel—I have no figures to prove it now—there is always more gas, whether it is oxygen or some other gas, more gas dissolved in the iron at high temperatures than at lower temperatures. This would be contrary to the original hypothesis upon which Johnson proceeded to carry out his tests and to prove that iron containing a greater amount of oxygen yielded stronger castings. Inasmuch as the authors have not explained fully just what does cause the greater strength of charcoal cast iron or coke cast iron, I was wondering whether or not we could proceed to work along

this line and ask this question: "Is it a fact that pig irons made at a lower temperature contain more oxygen?" I would venture to state from my previous experience that they contain less oxygen and it is because of lower oxygen content that charcoal irons are stronger.

DR. ECKMAN: As Mr. Waechter says, we do not show the reason for the greater strength of the charcoal iron. We wish we could, as it is the most important part of the whole subject, but it was not the aim of this rather limited paper. Our immediate problem was to determine the gas contents of the two kinds of iron and study the relation between the gas (particularly oxygen) content and the physical properties. Your question, "Does pig iron made at a lower temperature contain more oxygen?" is not easy to answer at this stage of our knowledge of the solubility of gases in metals. We think that helpful information might be obtained from the vacuum fusion determination of oxygen in *solid* samples of irons made at different temperatures. Johnson found that the iron made at lower temperatures was stronger, and showed higher oxygen content as determined by the Ledebur method. However, we feel that, owing to the inadequacy of the oxygen method used, Johnson's conclusion on the relation between oxygen content and strength may not be correct.

DR. MOLDENKE: The question Mr. Waechter brought up was a very interesting one, but you have not shown us the difference between charcoal iron and coke iron; if we knew that, we would think we knew something, but it is the one thing that makes us think we know very little. We do not know what we hope to know some day, we are away off from that yet. The other point I want to bring out is this: there may be two forms of oxygen in cast iron; there may be and, probably is, the dissolved ferrous oxide; there is also in there dissolved gas that has nothing to do with the structure, because it is held so tight; cast iron contains also a great deal of carbon monoxide. So your oxygen is made up of two oxygens, one from the gas in the iron which stays in there, and the other from the dissolved oxide of iron; so it had better be watched very carefully to see which is gas oxygen and which is dissolved oxide of iron. You will find very little ferrous oxide, but that very little may be tremendously effective.

The Influence of Phosphorus on the Total Carbon Content of Cast Iron

By James T. MacKenzie,* Birmingham, Ala.

The influence of phosphorous upon the total carbon content of cast iron was first noted by Stead[1] in 1900. He noted the cases of two pig irons of similar analysis, except for carbon and phosphorous, as follows:

	Silicon	*Sulfur*	*Mn.*	*P.*	*G. C.*	*C. C.*
Hematite Pig.....	2.80	.03	.85	.04	3.95	.15
Cleveland Pig.....	2.80	.03	.75	1.56	3.63	.12

The 1.56 phosphorous in the Cleveland pig being equivalent to about 10 per cent Fe_3P, the total carbon on the other 90 per cent would be 4.16 as against 4.10 for the hematite. Reasoning from this that pure iron should contain 4.60 carbon and Fe_3P none, he drew up a table showing the probable relation between phosphorous and total carbon. (Table 1.)

He checked his calculations by a series of melts made at one time in a five compartment crucible. (Table 2.)

In 1908, Wüst[2] published a much more comprehensive series of crucible melts with thermal data (not included here) showing the following relations: (Table 3.)

Table 3, "A" shows results on melts brought to 1300 degrees Cent. and allowed to cool slowly for the thermal investigation. The melts in Table 3, "B," were held at the freezing point (or just above) for one hour. Both sets were made under a cover of sugar carbon.

Coe[3] in 1914 obtained a very pure iron of the following analysis: Total Carbon 4.24; Silicon .95; Manganese .70; Sulfur .017; Phosphorous .025, and made a series of melts in crucibles which gave the values in Table 4.

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*American Cast Iron Pipe Co.

[1]Iron and Phosphorus. Jrnl. Iron and Steel Inst., 1900, Part 2.

[2]Beitrag zum Einfluss des Phosphors auf das System Eisen-Kohlenstoff.

[3]"Phosphorus in Cast Iron," Staffordshire Iron and Steel Institute, 1914.

Table 1

CALCULATED RELATION BETWEEN PHOSPHOROUS AND CARBON

Pure Iron	Phosphide	Phosphorous	Total Carbon
100	None	None	4.60
75	25	3.89	3.45
50	50	7.78	2.30
25	75	11.67	1.15
None	100	15.58	None

Table 2

OBSERVED RELATION BETWEEN PHOSPHOROUS AND CARBON

Phosphorous	Carbon
None	4.15
4.10	3.25
7.90	2.00
13.00	0.70
16 00	Nil.

Table 3

A		B	
P.	C.	P.	C.
.02	4.27	.02	4.27
.21	3.98	.07	4.22
.38	3.80	.28	4.04
1.21	3.61	.88	3.98
2.69	3.18	2.34	3.34
3.11	3.12	3.27	3.29
3.71	3.02	3.94	2.88
4.27	2.63	4.61	2.41
5.47	2.31	5.80	2.24
6.19	2.15	6.55	2.14
6.89	1.73	8.17	1.89
10.94	1.55	11.72	1.36
11.66	1.34	13.90	0.80
13.53	0.85	21.56	0.28
21.56	0.28		

Table 4

P.	C.
.025	4.23
.25	4.00
.45	4.04
.76	4.06
.84	4.00
1.07	4.01

Coe's results do not show any difference between .25 P. and 1.07 P. although by Stead's assumption the 1.07 P. should contain only 3.93 and the .25 P. should have 4.16 carbon. Some disturbing influence is probably responsible, although the .28 P. with only 4.04 carbon shown by Wüst seems to corroborate Coe, and his .88 P. with 3.98 C. is closer to Stead's figures for that phosphorous than to Coe's result.

All of these investigations were made in crucibles under laboratory conditions and the application of the principle to ordinary foundry practice does not appear to have been made by any writer on the subject known to the author. Johnson, in his book,[4] did not think enough of it to mention it, though he was familiar with it.[5] Moldenke[6] mentions only the effect of the two elements on the structural composition. Hatfield[7] gives a resume of Stead's work but does not apply it to foundry problems. Bolton,[8] discussing primarily the microstructure of cast iron, mentions Wüst's work quoted above, but in a later paper[9] gives a table showing lowering of deflection by phosphorous without mentioning its effect on the total carbon and without showing the carbon content of the bars. Hurst in a review[10] after quoting both Stead and Wüst says, "It may be taken as an axiom, however, that all other conditions being equal the lower the phosphorous the higher the strength and freedom from brittleness"—thus ignoring the influence of the phosphorous in preventing the foundrymen from keeping "all other conditions equal."

The present work was undertaken to see how small an increment of phosphorous would really affect the total carbon enough to count in the ordinary foundry processes, and how much would the net effect be on the fluidity and life of the molten iron, and on the strength, deflection and impact resistance of the test bars. Comparisons are often made between northern and southern irons —most frequently based on the superior deflection usually ob-

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[4]J. E. Johnson, Jr., The Principles, Operation and Products of the Blast Furnace.

[5]Trans. A. I. M. E., 1914, p. 380.

[6]Principles of Iron Founding.

[7]Cast Iron in the Light of Recent Research.

[8]Phosphorus Formations in Iron, The Foundry, L-787. 1922.

[9]Notes on Composition and Properties of the A. S. T. M. Bar, A. F. A., 1924.

[10]Influence of Phosphorus in Cast Iron, Foundry Trade Journal, 1924.

tained from the former. Almost without exception this is attributed to the higher manganese content of northern irons, but the writer believed that the influence of the phosphorus on the total carbon was a much more logical explanation, although the manganese also has an influence in the same direction in this case —the low manganese and high phosphorus irons from southern ores tending to low carbon, while the high manganese and low phosphorus northern irons tend to have higher carbons. Inasmuch as carbon is the chief, though unfortunately the most neglected, factor in the properties of gray iron, it is well to examine all the other elements as to their influence on the carbon first, and after that look for the individual effects.

The preliminary experiments were made in preparing a paper read by the author before the A. S. T. M. in 1924 on "'The Standard Test Bar for Cast Iron Pipe." This work was done solely with the view of establishing the variables which determined the deflection at 1900 pounds, or to speak more generally, the stress-strain curve for the 2 x 1 x 24 inch bar. In this work it appeared that every time phosphorous was added to an iron to determine its influence on the deflection, the deflection dropped but so did the carbon, and it was not apparent that it dropped any more than any other reduction of carbon would have accomplished.

Table 5 shows the results from melts of one car of iron of 0.8 per cent phosphorous, to the first two of which ferro-phosphorous was added in the cupola. The total carbons were lower than any of the other heats although they were both melted quite hot—especially No. 62 which was white hot. Heat No. 59, the lowest carbon from the normal phosphorous (3.40) was a melt with ferro-silicon in the charge and melts No. 66 (3.46 C.), 54 (3.45 C.) and 118 (3.46 C.) were all rather dull heats.

Table 6 shows comparative melts on another pig of .45 phosphorous where the drop in carbon caused by a .70 per cent addition of phosphorous in the cupola was 0.16 per cent. The temperature of the stream was 10 degrees Fahr. higher on No. 29 than it was on No. 13.

With this much to start on four lots of pig iron were obtained. "T. C. I." low phosphorous iron made from steel scrap

in a hot blast coke blast furnace by the T. C. I. & R. R. Co. for its ingot molds, analyzing: Si. 2.10; Sulfur .040; Mn. .70; P. .06; Carbon 4.05; Ti. .03; Vanadium .01. "A. E. P." a synthetic pig iron made in the basic electric furnace by the Anniston Electric Steel Corporation from steel scrap, containing: Si. 1.43; Sulfur .013; Mn. .52; P. .02; Carbon 3.07; Ti. .02; Vanadium .01. "B. M." a normal "malleable" pig iron made by the Brooke Malleable Iron Company in their furnace at Birdsboro, Pa., from Eastern ore and coke and a normal blast temperature of about 1100 degrees Fahr.,

Table 5

No.	Coke	T. C.	Silicon	Phosphorous	1500 pounds Defl.
55	A	3.34	1.83	1.36	.175
62	A	3.41	1.87	1.30	.195
68	A	3.50	1.93	.8	.20
67	A	3.53	1.95	.8	.205
122	B	3.53	1.97	.83	.21
66	A	3.46	2.05	.8	.21
54	A	3.45	1.82	.81	.21
61	A	3.53	1.96	.8	.21
58	A	3.52	1.87	.8	.215
118	A	3.46	1.95	.8	.22
59	A	3.40	2.30	.77	.22
57	A	3.51	1.95	.84	.225
119	A	3.65	1.94	.8	.24
120	A	3.48	1.94	.81	.245
121	A	3.59	2.16	.8	.26

Table 6

No.	Coke	T. C.	Silicon	Phosphorous	1500 pounds Defl.
13	P	3.73	2.34	.45	.36
29	P	3.57	2.20	1.12	.285

obtained through the courtesy of Messrs. Pilling of Philadelphia. This iron contained: Si. 1.94; Sulfur .035; Mn. .54; P. .19; Carbon 4.12; Ti. .09; Vanadium .03. "S. L S", a charcoal iron made by the Shelby Iron Company, Shelby, Ala., using charcoal with warm blast, unfortunately somewhat mixed, containing: Si. .99 to 1.34; Sulfur .030 to .053; Mn. .35 to .80; P. .33; Carbon 3.87; Ti. .02; Vanadium .01. "S. O. C.", an iron (Same as in Table 6) made by the Shelby Iron Co. using coke in the furnace containing: Si. 2.42; S. .050; Mn. .94; P. .45; C. 3.66; Ti. .07; Vanadium .02. In addition a high silicon iron from the furnaces of the Republic Iron and Steel Co., Birmingham, marked "R. H.

S." was used for a few melts. This is not an abnormal iron for these furnaces and the analysis was: Si. 4.70; S. .033; Mn. .73; P. .75; C. 2.99; Ti. .22; Vanadium .10.

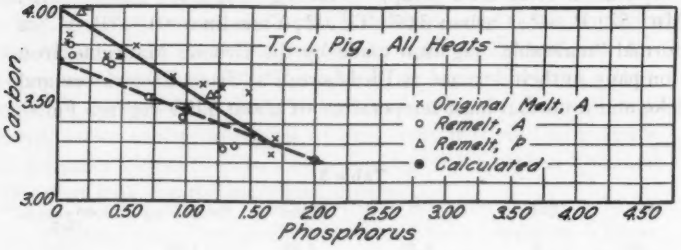

FIG. 1

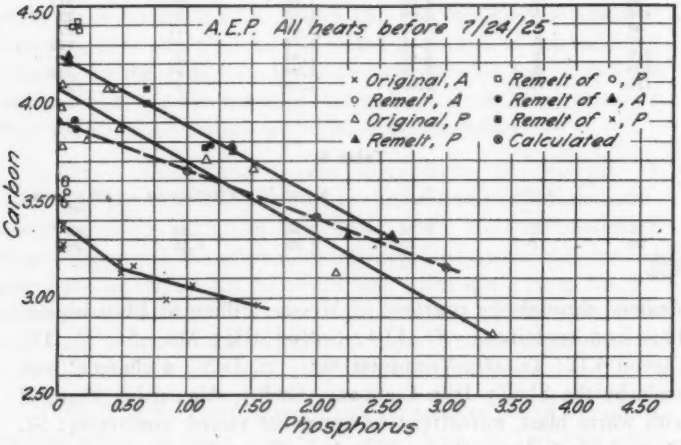

FIG. 2

All melts were made in an experimental Whiting Cupola, No. 0, with a fan blower giving about four to five ounces pressure. The bed was kept constant at thirty inches above the tuyere, which

gave some 50 pounds of iron in twenty minutes from the beginning of the blow, and melting usually proceeded at the rate of 100 pounds every five minutes, which is 20 per cent above the rated capacity. A shank ladle of 170 to 180 pounds capacity was used and as the charges were kept within 15 per cent of 100 pounds taps were usually made every five minutes, being approximately a charge to the tap. The first iron was discarded in all cases and where the stock was plentiful the bars were not poured until the third or fourth tap. Only a few cases of trouble were encountered which was invariably from bridging. Unless the coke was well broken up it would bridge in lighting off, and when the wind went on it would drop.

In the first heat on the Anniston pig which was extremely hard to break, and so charged in too great lengths, the coke dropped a foot about ten minutes after the blast went on, and later, the pig scaffolded and had to be knocked down with bars before melting could proceed. This was the worst heat in the lot, and of course it had to happen with the low carbon material. In some heats small taps were taken for a survey knowing that the analysis would not be uniform. Previous experiments had shown that the fan blower began to deliver considerably more air as the stock sank in the stack, so a heavy charge of coke was always put on top of the last iron, and in some of the later melts the stack was kept full of coke until the heat was concluded. This very effectively maintained uniformity of blast throughout the melt.

The cokes used were:

		Per Cent Ash	Per Cent S.
"A"	By-Product (Alabama By-Products Co.)	10.0	0.6
"P"	Queen Bee (Barrett Co.—Pitch).....	0.4	0.4
"D"	Beehive 96 Hour	17.0	1.7
"B"	Beehive 72 Hour	4.0	0.5

The cupola was not slagged on any heat.

The method of molding and breaking the bars with the methods of sampling and analysis are as described in the previously mentioned paper (A. S. T. M. Trans., Vol. 24, Part II, pp. 664)

except that a chromic-sulfuric acid bulb was substituted for the zinc and phosphorous towers in the carbon train. The drop test was made on the broken halves of the bars laid flatwise on supports six inches apart. The weight of 25 pounds was dropped from an initial height of eight inches and then from successive half inch increments until failure occurred, the height of the final blow only being recorded.

On the few sets reported as breaking below eight inches, the first drop was made at four inches and similarly increased. Most of the sets were of three bars, some few of only two, and quite a number of five. One lower half from each set was set aside as a keep-sake and the remaining halves were broken under the drop.

In many cases a half bar could be broken twice if the results were not concordant, and this was often done as flaws, however small, play havoc with this test. One or two flaws in a good set were discarded, but in a few cases there were so many they had to be considered normal to the set and were included in the average.

Table 7 contains all the data recorded in the investigation. The date of casting followed by the letter indicating the coke used, and the mix in pounds per charge are shown initially. Then the order in which the samples were tapped with the number of the test bar set in its proper position. The total carbon is followed immediately by the phosphorous for convenient observation with the silicon following these as the next element of importance.

Sulfur evolved as hydrogen sulfide (theoretical titre used: Potassium Iodate, Sodium Thiosulfate, Potassium Permanganate, Sodium Oxalate—U. S. B. S. No. 40) and the oxidation sulfurs are given on all sets of bars, and the evolution sulfurs are also given on a great many of the other samples, especially the first tap, as there is an impression that the very first iron is high in sulfur, an impression which the writer has never been able to verify. Both sulfur and manganese are shown, though they do not seem to have much bearing on the present subject, largely to make the data complete and partly because they are very little trouble to run.

Table 7

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
1/5 A	1	3.83	.06	1.93		.61								
T. C. I. 100	154	3.86	.08	1.88	.052	.59	3.04	.82	.064	.275		1820	.38	
1/13A	1	3.75	.10	1.62		.51								
T. C. I. 33, Scrap 1/5—67	159	3.80	.09	1.75	.062	.54	3.00	.80	.070	.27	.40	1960	.43	
1/17 P	1	3.97	.16	1.60		.42								
Remelt of 1/13	163	4.00	.22	1.62	.070	.40	3.18	.82	.079	.25	.35	2140	.45	12.5
1/6 A	1	3.75	.37	1.75		.62								
T. C. I. 100, FeP 2	155	3.75	.48	1.84	.058	.61	2.96	.79	.060	.21	.30	2100	.37	
	3	3.75	.47	1.81		.62								
1/14 A	1	3.70	.41	1.49		.56								
TCI 33, Scrap 1/6, 67 FeP 2	160	3.72	.36	1.65	.054	.54	2.89	.83	.064	.21	.29	2200	.36	
1/7 A	1	3.80	.60	1.58		.57								
TCI 100, FeP4	156	3.65	.89	1.70	.057	.57	2.88	.77	.070	.18	.24	2300	.33	10
1/15 A	1	3.54	.70	2.16		.48								
TCI 33,Scrap 1/7 67 FeP 1,FeSi 1.	161	3.54	.72	2.12	.055	.52	2.81	.73	.077	.19	.26	2250	.32	10
1/8 A	1	3.60	1.12	1.61		.59								
TCI 100, FeP 6	157	3.58	1.27	1.60	.057	.60	2.82	.76	.066	.18	.24	2190	.29	9
1/12 A	1	3.25	1.65	1.98		.45								
TCI 100, FeP 10, FeSi 0.6	158	3.34	1.69	1.93	.070	.50	2.69	.65	.078	.16	.20	2600	.33	9.5
	3	3.56	1.48	2.04		.51								
1/16 A	1	3.29	1.37	2.13		.41								
TCI 33, Scrap 1/12 67	162	3.27	1.28	2.14	.063	.46	2.65	.62	.091	.17	.22	2330	.28	
FeP 3, FeSi 1	3	3.43	.97	2.36		.47								
1/18 P	1	3.55	1.19	2.10	.076	.35								
Remelt of 1/16	164	3.55	1.23	2.07	.077	.39	2.85	.70	.087	.185	.25	2580	.37	11
2/10 A	1	3.28	.04	1.30	.034	.42								
AEP 100	165	3.27	.04	1.31	.029	.46	2.32	1.05	.026	.155	.20	3180	.44	
Sluggish Heat	3	3.38	.04	1.30	.033	.42								
2/11 A	1	3.38	.04	1.33	.035	.42								
AEP 100	166	3.53	.04	1.32	.037	.46	2.65	.88	.039	.17	.24	2900	.45	

(Continued on next page)

Table 7
(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per Cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
2/14 A	1	3.49	.06	.80	.059	.30								
Scrap 2/10 50	169A	3.55	.07	.94	.062	.29	2.01	1.54	.072	.13	.16	2500	.22	
Scrap 2/11 50	169B	3.61	.06	1.20	.071	.34	2.43	1.18	.079	.16	.21	2600	.35	
	169C	3.59	.06	1.27	.067	.36	2.55	1.04	.077	.17	.22	2750	.40	
2/21 P	1	4.40	.11	.97	.070	.22								
Remelt of 2/14	175	4.38	.17	1.03	.072	.22	2.98	1.40	.084	.25	.36	2250	.51	13
	3	4.42	.15	.96	.073	.22								
2/16 P	1	4.10	.04	1.27		.51								
AEP 100	170	3.96	.03	1.38	.030	.51	3.02	.94	.028	.29	.42	1940	.44	
	3	3.77	.03	1.30		.48								
2/20 P	1	4.25	.08	1.23		.39								
Remelt of 2/16	174	4.23	.08	1.30	.041	.36	3.35	.88	.042	.34	.53	1950	.54	
	3	4.22	.08	1.24		.36								
3/5 A	1	3.86	.14	1.00		.24								
Remelt of 2/20	185	3.92	.13	1.10	.082	.22	2.67	1.25	.088	.23	.32	2200	.40	10.5
2/12 A	1	3.13	.49	1.25	.030	.43								
AEP 100, FeP 5	167	3.17	.50	1.31	.043	.43	2.16	1.01	.046	.14	.18	3300	.34	
FeSi 0.4, FeMn 0.03	3	3.00	.85	1.29	.044	.40								
2/28 P	1	4.08	.68	1.12		.32								
Remelt of 2/12	181	4.00	.69	1.22	.065	.35	3.00	1.00	.071	.21	.29	2300	.38	11
2/17 P	1	4.08	.45	1.30		1.16								
AEP 100, FeP 5	171	3.66	1.51	1.29	.051	.54	2.85	.81	.054	.16	.20	2700	.32	10.5
FeSi 0.2, FeMn 0.03	3	3.81	.23	1.27		.52								
2/13 A	1	3.19	.48	1.40		.54								
AEP 100, FeP 10	168	2.96	1.55	1.26	.041	.42	2.05	.91	.048	.13	.17	2900	.24	
FeSi 0.4, FeMn 0.05	3	3.06	1.04	1.33		.43								
3/2 P	1	3.79	1.18	1.13		.32								
Remelt of 2/13	182	3.77	1.14	1.13	.055	.34	2.90	.87	.061	.16	.21	2900	.37	11.5
2/18 P	1	4.08	.39	1.38		.48								
AEP 100, FeP 10	172	3.34	2.52	1.52	.062	.44	2.53	.81	.074	.145	.19	2500	.24	
FeSi 0.4, FeMn 0.05	3	3.71	1.15	1.50		.44								

(Continued on next page)

Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G C..	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
3/3 P	1	3.78	1.35	1.24		.35								
Remelt of 2/18	183	3.76	1.37	1.30	.053	.34	3.05	.71	.057	.19	.25	2320	.33	11
2/19 P	1	3.86	.48	1.43		.47								
AEP 100, FeP 15	173	3.14	2.16	1.41	.049	.46	2.33	.81	.059	.13	.17	2500	.23	
FeSi 0.8, FeMn 0.1	3	2.82	3.36	1.24		.40								
3/4 P	1	3.52	2.58	1.10		.31								
Remelt of 2/19	184	3.42	2.25	1.20	.061	.37	2.55	.87	.068	.145	.18	2470	.24	10
7/29 A	1			.97		.32								
AEP 100, FeP 2.5 for five charges	2	3.37	.46	1.08	.040	.34								
then three charges of straight	3	3.14	1.09	1.18		.39								
pig	297	3.23	1.07	1.29	.045	.38	2.55	.68	.049	.145	.19	2900	.30	12
	298	3.29	.81	1.33	.044	.44	2.53	.76	.046	.145	.19	3000	.33	13.5
Cupola hung up several times dur-	6	3.54	.79	1.34		.40								
ing run	299	3.50	.14	1.37	.040	.39	2.89	.61	.040	.18	.25	2700	.43	16
	8	3.22	.03	1.40		.41								
7/31 B–P	1	3.70	.54	1.30	.074	.31								
Scrap of 7/29 100	2	3.69	.46	1.36		.30								
FeSi 0.5, FeMn 0.06	302	3.72	.50	1.33	.066	.36	2.87	.85	.078	.195	.27	2650	.44	12
Coke "B" only from 4	4	3.56	.46	1.27		.30								
	303	3.59	.82	1.43	.067	.31	2.73	.86	.082	.17	.23	2680	.35	12.5
	6	3.54	.91	1.40		.28								
8/3 P	1	3.99	.62	1.49	.067	.37								
Remelt of 7/31	2	4.22	.59	1.49		.33								
FeSi 0.5, FeMn 0.06	306	4.07	.57	1.49	.072	.31	3.30	.77	.091	.27	.37	2200	.49	11
	307	3.93	.57	1.48	.074	.30	3.06	.87	.092	.22	.30	2400	.44	12.5
	4	4.04	.59	1.58		.34								
	5	4.14	.59	1.71	.073	.30								
8/8 B–P	1	3.77	1.18	1.39	.054	.45								
AEP with FeP diminishing from	2	3.94	.79	1.38		.44								
5% on first charge to none on	3	3.99	.37	1.41		.42								
last three	312	3.73	.79	1.38	.045	.42	2.91	.82	.045	.17	.23	2500	.33	12
	5	3.66	.76	1.35		.44								

(Continued on next page)

Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
Proportion of pitch coke reduced from 75% to 0 as heat progressed	313	3.79	.38	1.39	.043	.42	3.02	.77	.042	.20	.28	2470	.43	13
	7	Sample lost												
	314	3.73	.14	1.39	.032	.42	2.92	.81	.032	.205	.29	2600	.50	13.5
	315	3.44	.04	1.38	.029	.43	2.60	.84	.029	.165	.21	2900	.42	17
	10	3.38	.03	1.41										
3/6 A	1	3.76	.35	.84	.063	.34								
SLS 100	2	3.78		.85		.30								
FeSi 0.5, FeMn 0.05	186	3.78	.35	.92	.075	.34	2.93	.85	.080	.19	.24	2800	.47	16
	4	3.78		1.25		.43								
	187	3.80	.35	1.51	.066	.43	2.98	.82	.072	.24	.36	2220	.49	14.5
	6	3.84		1.10		.33								
	7	3.77	.36	.90		.33								
	8	3.80		.97	.070	.34								
3/10 A	1	3.75	.36	1.11		.25								
Remelt of 3/6	190	3.85	.36	1.05	.087	.33	2.73	1.12	.103	.185	.26	2600	.41	12.5
	3	3.78	.36	1.05		.28								
3/11 P	1	Sample lost												
Scrap of 3/6 100	191	3.95	1.20	1.03	.091	.32	2.91	1.04	.109	.20	.27	2340	.37	10
FeP 5, FeSi 0.2, FeMn 0.03	3	3.90	1.39	.95		.34								
2/23 P	1	4.31	.35	.79	.055	.34								
SLS 100	2	4.22	.36	.83		.34								
	176	4.16	.35	.98	.054	.47	3.37	.79	.060	.27	.40	2100	.50	
	4	4.20	.36	1.08		.56								
2/27 P	1	4.28	.38	.85		.37								
Remelt of 2/23	180	4.33	.39	.91	.073	.38	3.38	.95	.078	.30	.45	2000	.51	12.5
2/24 P	1	4.35	.35	1.16		.65								
SLS 100, FeP 5	177	3.94	1.11	1.06	.059	.53	3.10	.84	.070	.20	.28	2260	.36	10
FeSi 0.2, FeMn 0.03	3	4.04	1.10	.95		.42								
	4	3.95	1.50	1.01		.46								
2/25 P	1	4.21	.55	1.32		.55								
SLS 100, FeP10	178	3.80	1.48	1.31	.073	.52	3.14	.66	.080	.195	.27	2100	.31	9
FeSi 0.5, FeMn 0.06	3	3.52	2.44	1.14		.39								
	4	3.63	2.29	1.09		.40								

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Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
2/26 P	1	4.26	.57	1.13	.054	.59								
SLS 100, FeP 15	2	3.83	1.40	1.06		.49								
FeSi 0.8, FeMn 0.1	179	3.00	3.55	.92	.132	.46	2.45	.55	.146	.165		1580	.17	5
	4	3.55	2.34	1.15		.42								
3/16 A	195	3.48	2.01	.80	.105	.42	2.41	1.07	.133	.14	.18	2700	.25	8.5
Remelt of 2/26	3	3.50	1.99	.89		.44								
3/7 A	1	3.53	.41	2.03	.064	.61								
SOC 100	2	3.56		2.43		.72								
	188	3.50	.42	2.34	.077	.61	2.87	.63	.087	.22	.31	2340	.44	13.5
	4	3.48		2.46		.67								
	5	3.49		2.48		.68								
	6	3.46		2.49		.72								
	7	3.45	.44	2.06	.093	.55								
3/13 A	1	3.46	.48	2.07		.55								
Remelt of 3/7	193	3.53	.46	2.08	.082	.51	2.79	.74	.101	.22	.31	2290	.40	13.5
	3	3.55	.43	2.16		.53								
3/12 P	1	4.06	.47	2.32	.059	.56								
Scrap of 3/7 100, FeP 5	2	4.13	.50	2.22		.50								
FeSi 0.2, FeMn 0.03	192	3.76	1.53	2.10	.087	.51	3.10	.66	.102	.30		1800	.39	9
	4	3.47	2.12	2.05		.53								
3/14 D	1	3.22	1.45	1.94	.118	.40								
SOC 50, FeP 7	2	3.31	1.27	2.02	.121	.57								
Scrap 3/12 25, Scrap 3/13 25	194	3.29	1.43	2.09	.127	.57	2.76	.53	.163	.18	.24	2140	.28	10.5
	4	3.20	1.71	1.93	.145	.50								
	5	3.16	1.92	1.86	.160	.41								
3/17 P	1	3.66	1.46	1.90		.44								
Remelt of 3/14	196	3.54	1.50	1.96	.111	.39	2.72	.82	.153	.20	.27	2130	.33	9.5
	3	3.75	1.53	2.02		.50								
	4	3.50	1.53	2.09		.38								
3/18 A	1	3.29	1.48	1.81	.088	.36								
Remelt of 3/17	2	3.26	1.49	1.91		.33								
	197	3.27	1.52	2.02	.114	.36	2.63	.64	.141	.18	.24	2150	.28	9.5
	4	3.25	1.50	2.02		.30								

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Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
3/30 A	1	2.69	.81	4.60	.048									
RHS 170	208	2.74	.76	4.53	.050	.65	2.40	.34	.048	.185	.24	2600	.35	11
Steel 10	3	2.82	.74	4.30										
	4	2.84	.81	4.65										
4/1 P	1	3.32	.85	4.30	.043									
Remelt of 3/30	2	3.45	.76	4.31										
	210	3.28	.79	4.31	.055	.54	3.16	.12	.044	.44		1780	.58	10
	4	3.37	.76	4.39										
4/28 D	1	2.93		4.20	.110									
Remelt of 4/1	2	2.99		4.19										
	217	3.03	.81	4.20	.110	.47	2.82	.21	.120	.29	.40	1820	.38	9
3/31 A	1	2.71	1.59	4.37	.056									
RHS 170	2	2.59	2.21	4.31										
FeP 10	209	2.64	2.22	4.20	.063	.64	2.43	.21	.063	.25		1530	.26	8.5
	4	2.83	1.35	4.36										
4/2 P	1	3.10	1.76	4.14	.051									
Remelt of 3/31	2	3.30	1.68	4.18										
	211	3.23	1.76	4.25	.055	.59	3.00	.23	.048			1320	.28	7.5
	4	3.10	1.77	4.17										
4/29 D	1	2.62		4.23	.115									
Remelt of 4/2	2	2.79		4.21										
	218	2.71	1.80	4.14	.115	.45	2.53	.18	.130	.215	.29	2100	.33	9
6/8 A	1	3.70	.19	1.71	.047	.42								
BM 100	2	3.78	.19	1.82		.44								
	235	3.78	.20	1.93	.050	.50	2.97	.81	.057	.33		1760	.42	11
	4	3.88	.19	1.97		.46								
	236	3.74	.20	2.05	.053	.48	3.05	.69	.056	.34		1790	.44	11
6/19 A	253	3.58	.21	1.73	.086	.37	2.79	.79	.094	.21	.30	2260	.40	14.5
Remelt of 6/8	254	3.63	.20	1.82	.061	.36	2.92	.71	.076	.26	.39	2070	.45	13
6/9 A	1	3.62	.18	1.51	.042	.40								
BM 95, Steel 5	2	3.69	.19	1.68		.38								
	237	3.73	.19	1.79	.055	.46	3.00	.73	.058	.32		1700	.39	11
	5	3.71	.18	1.83		.43								
	6	3.86	.19	1.87	.055	.43								

(Continued on next page)

Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
6/15 A	1	3.26	1.67	1.56	.085	.38								
BM 95, PeP 5	2	3.64	.64	1.84		.44								
	245	3.50	.95	1.85	.073	.46	2.81	.69	.075	.23	.31	2060	.35	11
	4	3.57	1.43	1.81		.44								
	246	3.50	1.28	1.69	.076	.45	2.91	.59	.094	.22	.30	2100	.36	11
	6	3.72	.59	1.72		.45								
	7	3.76	.66	1.85	.050	.45								
6/20 A	255	3.64	.21	1.70	.086	.32	2.82	.82	.096	.21	.30	2350	.44	14
Remelt of 6/9	256	3.63	.20	1.60	.069	.33	2.81	.82	.072	.22	.31	2350	.45	14
6/24 A	261	3.43	.89	1.61	.084	.34	2.68	.75	.105	.18	.24	2430	.35	11
Remelt of 6/15	262	3.47	1.03	1.73	.083	.34	2.73	.74	.110	.19	.26	2290	.34	10
6/10 A	1	3.51	.17	1.58	.058	.40								
BM 90, Steel 10	2	3.65	.18	1.81		.43								
	238	3.54	.17	1.66	.053	.43	2.74	.80	.070	.21	.31	2490	.48	15
	4	3.72	.19	1.82		.41								
	239	3.51	.17	1.63	.063	.40	2.78	.73	.072	.20	.29	2560	.49	15
	6	3.56	.17	1.81		.42								
6/18 A	1	3.57	.33	1.61	.050	.41								
BM 90 Steel 10	2	3.69	.24	1.70		.45								
	251	3.57	.23	1.68	.054	.41	2.87	.70	.056	.21	.30	2320	.41	15
	4	3.74	.24	1.79		.45								
	252	3.62	.23	1.76	.058	.40	2.93	.69	.064	.23	.34	2220	.44	14
	6	3.52	.19	1.53		.44								
6/16 A	1	2.96	4.15	1.32	.120	.38								
BM 90, PeP 10	2	3.29	2.72	1.46		.41								
	247	3.43	1.30	1.75	.068	.41	2.85	.58	.082	.22	.31	2000	.32	10.5
	4	3.36	1.99	1.67		.39								
	248	3.25	2.48	1.64	.099	.40	2.73	.52	.108	.20		1700	.24	8
	6	3.55	1.43	1.62		.43								
6/22 A	257	3.57	.18	1.55	.082	.31	2.75	.82	.098	.19	.26	2320	.36	15.5
Remelt of 6/10	258	3.50	.19	1.57	.085	.31	2.68	.82	.100	.20	.28	2460	.41	13.5
6/27 A	267	3.64	.24	1.57	.078	.34	2.79	.85	.100	.20	.28	2420	.42	14
Remelt of 6/18	268	3.62	.26	1.63	.076	.36	2.83	.79	.089	.22	.31	2420	.44	14

(Continued on next page)

Table 7

(Continued)

Heat Data	Tap No.	T. C. Per cent	Phos. Per cent	Si.	Ev. S.	Mn.	G. C.	C. C.	Ox. S.	1500	1900	Ultimate Strength Pounds	Deflection in Inches	Drop
6/25 A	1	3.06	2.16	1.49	.081	.30								
Remelt of 6/16	2	3.11	2.16	1.55		.30								
	263	3.11	2.28	1.50	.094	.30	2.40	.71	.127	.16	.21	1960	.23	8
	4	3.12	2.27	1.48		.34								
	264	3.10	2.59	1.50	.098	.30	2.46	.64	.129	.17	.21	2000	.24	8
	6	3.09	2.40	1.55		.34								
6/13 A	1	3.54	.17	1.43	.059	.38								
BM 85, Steel 15	2	3.55	.16	1.47		.42								
	243	3.61	.18	1.66	.062	.41	2.91	.70	.071	.23	.34	2230	.48	15
	4	3.71	.18	1.68		.41								
	244	3.69	.18	1.78	.051	.47	2.99	.70	.071	.31		1800	.43	11.5
	6	3.61	.17	1.54		.39								
6/17 A	1	3.39	2.09	1.53	.078	.39								
BM 85, FeP 15	2	3.21	2.93	1.53		.39								
	249	3.22	2.85	1.53	.104	.41	2.67	.55	.125	.20		1700	.22	8
	4	3.25	2.90	1.53		.38								
	250	3.34	1.82	1.65	.090	.43	2.79	.55	.096	.21	.29	1980	.30	9.5
	6	3.06	3.39	1.50		.38								
6/23 A	259	3.64	.17	1.50	.094	.26	2.52	1.12	.118	.21	.29	2360	.39	12.5
Remelt of 6/13	260	3.47	.17	1.53	.084	.34	2.66	.81	.110	.19	.28	2540	.46	14.5
6/26 A	1	2.97	2.57	1.35	.084	.27								
Remelt of 6/17	2	2.98	2.63	1.35		.27								
	265	3.05	2.59	1.45	.099	.31	2.36	.69	.128	.165		1830	.21	8
	4	3.02	2.49	1.46		.29								
	266	3.06	2.45	1.51	.110	.30	2.33	.73	.143	.165		1770	.20	8
	6	3.01	2.41	1.47		.30								
6/29 P	1	3.40	2.38	1.38	.083	.28								
Scrap of 6/25 50	2	3.42	2.43	1.45		.23								
Scrap of 6/26 50	269	3.42	2.40	1.44	.098	.21	2.58	.82	.124			1380	.20	8
	270	3.25	2.39	1.40	.095	.22	2.42	.83	.129			1490	.19	8
	5	3.30	2.43	1.42		.26								
	271	3.42	2.33	1.43	.116	.23	2.48	.94	.129	.20		1500	.20	8
	7	3.25	2.33	1.42		.22								

It appeared worth while to include the oxidation sulfurs on the test bars as the determination is rarely made and no doubt many foundrymen will be glad to have these comparative results.

Graphitic carbon was run on the bars only as the other sam-

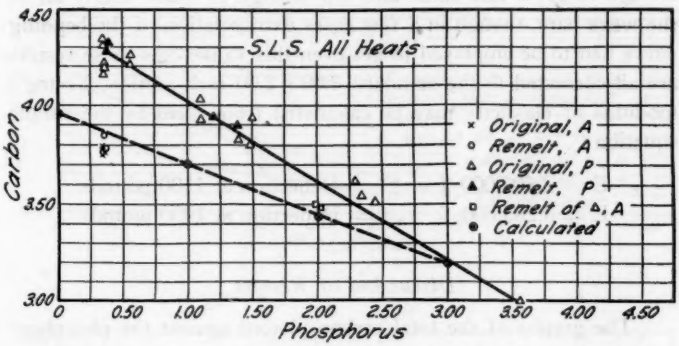

FIG. 3

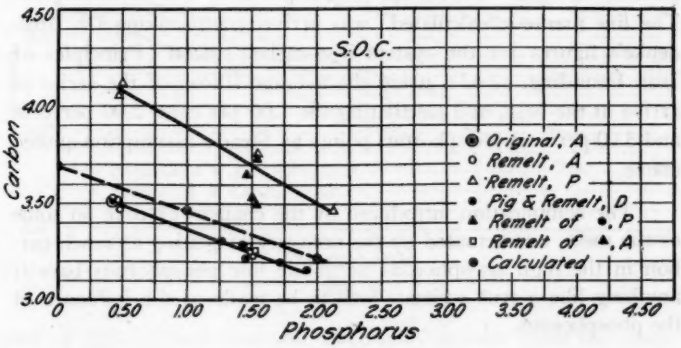

FIG. 4

ples were poured into all kinds of shapes and sizes including chill molds for arbors, which would make them worthless. Titanium and vanadium were run only on the original raw materials and could not be present in disturbing amounts except possibly in the "R. H. S." melts.

The results on the bars shown in addition to the ultimate breaking load and deflection are the drop test, where made—and the deflection at 1500 pounds and at 1900 pounds. The 1900 pound point is included for the cast iron pipe makers and the 1500 pound point is used for the general comparison as it is high enough to get a fair value and low enough to reach nearly all of the weak bars, though in a few cases extrapolation of the bending curve had to be employed to get even this value. As these results are all corrected to the standard 1.00 x 2.00 inch section, Young's modulus of elasticity may be calculated from them by the simple equation:

$E = 2{,}592{,}000/f$ $\quad f =$ Deflection at 1500 pounds
$E = 3{,}283{,}000/f$ $\quad f =$ Deflection at 1900 pounds

Discussion of Results

The graphs of the total carbon plotted against the phosphorous are shown in Figs. 1 to 6. The notation becomes quite complicated on some of them but it is hoped they will be intelligible. The line marked "calculated" was arrived at by taking Dr. Moldenke's figures for the system iron-carbon-silicon (Principles of Iron Founding, p. 42), using the average silicon of the series to arrive at the base, and calculating the 1.00 per cent, 2.00 per cent and 3.00 per cent phosphorous points by Stead's assumption quoted above.

The complication introduced by the changes of coke on some of the melts was actuated by the necessity of getting as much carbon in the high phosphorous as in the low phosphorous bars if anything like a true estimate was to be made of the influence of the phosphorous.

The graphs scarcely need discussion if it be borne in mind that there was considerable variation in the Shelby low silicon pig itself; that the Anniston electric pig had only 3.07 carbon to start with and was therefore very sensitive to cupola conditions, and that it was impossible to break it but once which disturbed those conditions seriously; and that many of the melts with pitch coke

were hyper-eutectic and gave much trouble in pouring from the continuous elimination of graphite, which is a familiar phenomenon around the blast furnace, but not so familiar at the cupola. A striking instance of this is found in the sets No. 306 and 307,

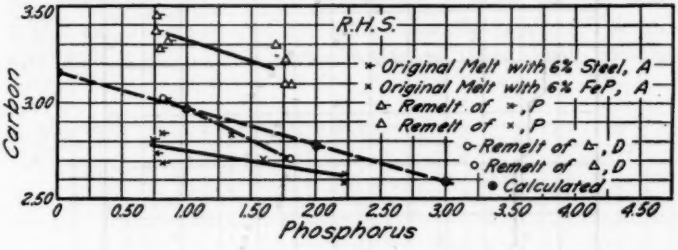

FIG. 5

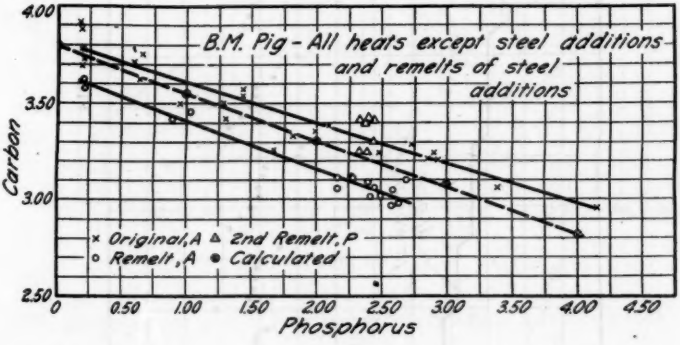

FIG. 6

cast of 8/3. These two sets were both poured from the same ladle of iron. After 306 was poured the ladle was stirred with a steel rod for two minutes and 307 was poured. The total carbon dropped from 4.07 to 3.93, the graphite from 3.30 to 3.06, the deflection at 1500 pounds from .27 to .22, the breaking load rose from 2200 to 2400 pounds, and the drop test went from 11 to 12.5 inches. These four carbons were very carefully checked; the results above being the average of four closely agreeing determina-

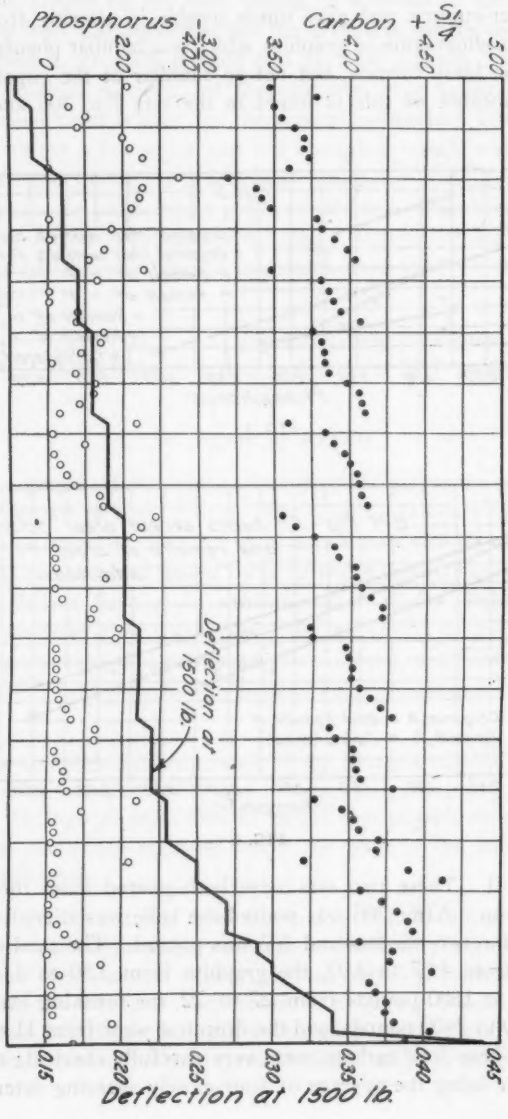
Phosphorus
Carbon + Si/4
0
2.00
3.00
4.00
3.50
4.00
4.50
5.00
Deflection at 1500 lb.
.15
.20
.25
.30
.35
.40
.45
Deflection at 1500 lb.

FIG. 7

tions of the total and three of the graphitic carbons. Three bars were poured in each set. This was the only comparative test made on this point but many other melts gave off graphite more copiously than this one, notably the melt of 4/2 and that of 2/27. In the heat of 3/17, the iron for the bars (196) and for the fourth tap was allowed to cool before being poured, while Nos. 1 and 3 were poured into chills as soon as tapped. The former show 3.50 and 3.54 carbon while the latter show 3.66 and

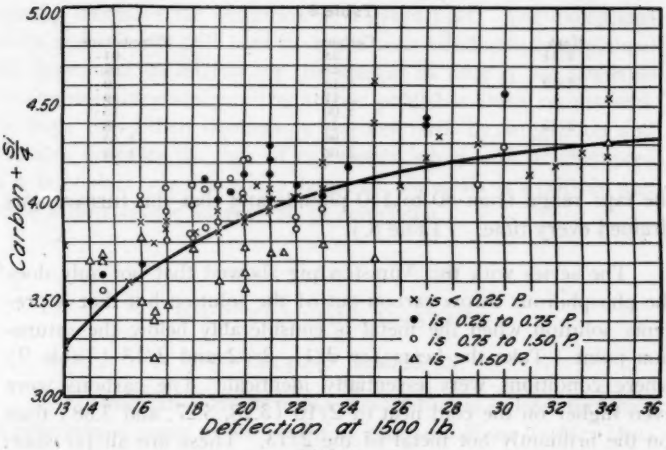

FIG. 8

3.75, phosphorous and silicon being practically constant throughout the melt.

The general principle enunciated by Stead seems to be amply borne out even under the complex conditions of cupola practice. When these conditions are kept uniform the phosphorous acts directly according to Stead's law and in case of appreciable amounts of phosphorous it is practically impossible to overcome its influence, for the hyper-eutectic irons would be worthless in the foundry on account of their sluggishness. Just a few heats may be cited to show how rapidly this metalloid acts, remembering that

Table 8

Heat	Tap	Carbon	Phosphorous
3/12	2	4.13	.50
	3	3.76	1.53
	4	3.47	2.12
2/26	1	4.26	.57
	2	3.83	1.40
	3	3.00	3.55
	4	3.55	2.34
2/19	1	3.86	.48
	2	3.14	2.16
	3	2.82	3.36
2/18	1	4.08	.39
	2	3.34	2.52
	3	3.71	1.15

Table 9

Heat	Carbon	Phosphorous
2/11	3.38	.04
	3.53	.04
2/12	3.13	.49
	3.17	.59
	3.00	.85
2/13	3.19	.48
	2.96	1.55
	3.06	1.04

the taps range from 60 to 150 pounds and that the furnace was drained every time. (Table 8.)

The series with the Anniston pig showed that not only does the phosphorous throw carbon out of the solution but that it prevents solution when the metal is considerably below the saturation point. Take the heats for 2/11, 2/12 and 2/13 (Table 9) where conditions were essentially identical. The carbons were even higher on the cold heat of 2/10 (3.28, 3.27, and 3.38) than on the brilliantly hot metal of the 2/13. These are all far short of their carbon saturation point which is shown in Fig. 2. This experience is corroborated by Coe[11] who working in crucibles with a 3.0 per cent carbon iron dropped off to 2.48 C. with 2.0 P., 2.41 C. with 1.75 P. and 2.42 C. with 2.88 P.

Fig. 7 shows the results for carbon plus one-fourth silicon, phosphorous, and the deflection at 1500 pounds plotted for each set of bars arranged in the order of their deflection at 1500 pounds. Fig. 8 shows the carbon plus one-fourth silicon against the deflection with the approximate phosphorous content denoted by the characters. The line drawn on Fig. 8 is taken from the graph shown in the A. S. T. M. paper by the author, previously

[11]See footnote 3.

mentioned. These graphs are published with considerable hesitation as they are at variance with the general belief and with Wüst's monumental work[12] but they are too striking to omit.

In Fig. 7 except for the first sets, deflection .13 and .14, the high phosphorous bars have much lower C. plus Si/4 for a given deflection than the medium and low phosphorous bars, and the abnormally high values for C. plus Si/4 are almost without exception accompanied by low phosphorous. In Fig. 8, the wildest results are those for the low phosphorous above the line and for the high phosphorous below the line indicating that phosphorous actually increases the deflection at a given load. The exceptions which occur in the stiff bars have not been satisfactorily explained and they must be left so for the present as time is not available for the necessary study. The author publishes these results with the hope that other workers in the field will by suggestion and criticism facilitate the task of correlation which will be attempted at a later date when a wider range of materials is available and when a microscopic survey can be completed.

WRITTEN DISCUSSION

J. W. Bolton,* Moline, Ill.

The American Foundrymen's Association is indeed fortunate in obtaining a paper of the worth of that just given by Mr. MacKenzie. Even superficial study reveals the fundamental character of the research revealed in this contribution.

Before proceeding to discussion of the paper proper, we venture to sound the keynote of gray iron research of today, and that is that structural analysis is the factor which is of primary importance. Chemical analysis, alone, fails. The reason is not far to seek. It is inexorably true that the properties of any material must depend upon its structural make-up. In case of gray iron we must deal with the factors of composition and temperature and their result—namely, structural make-up. Our distinguished

[12] "Einfluss des Phosphors auf die Mechanischen Eigenschaften des Grauen Gusseisens" (Ferrum, Vol. XII, 7-1925).

*Frank Foundries Corp.

guest, J. E. Fletcher, called this to our attention in the splendid British exchange paper. It is self-evident from study of Mr. MacKenzie's paper, and indeed we find the trend of nearly all modern papers is in this direction.

Mr. MacKenzie calls to our attention the very comprehensive work of Professor Wüst. This research, as is intimated from its title, deals with the effect of phosphorus upon the system iron

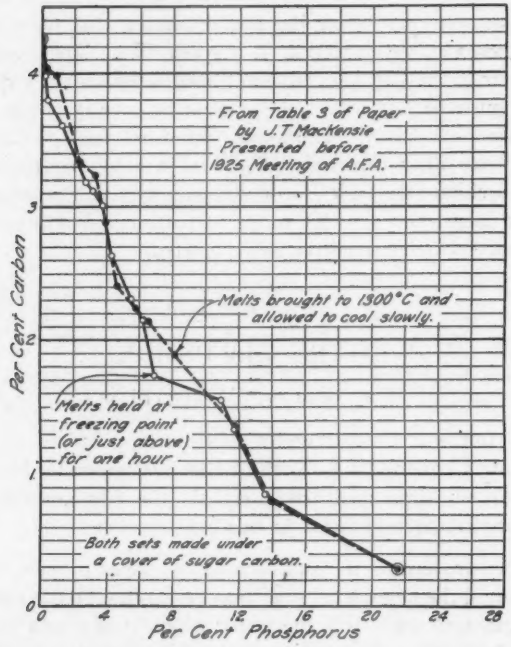

FIG. 1—DATA GIVEN BY WUST PLOTTED—JOURNAL IRON AND STEEL INSTITUTE, 1900, PART 2.

carbon. The particular table (Table 3 of MacKenzie's paper) reproduced indicates the effect of phosphorus upon the cast iron eutectic, rather than the effect of phosphorus upon melting point. Plotting these figures gives a very significant curve (Fig. 1 of

this discussion) one which correlates excellently with those researches upon phosphorus conducted in our laboratory. In our papers, referred to by Mr. MacKenzie on page 447, we followed the microstructure and physical properties of commercial irons of various phosphorus content, irons ranging from .20 to .70

Table 1
PHOSPHORUS—DEFLECTION
Summary of Test Bar Data

Deflection in Inches	No. of Test Bars Broken	Average Total Carbon Percent	Average Silicon Percent	Average Phosphorus Percent	Average Manganese Percent	Average Sulphur Percent	Average Transverse Strength	Carbon + Silicon
.090	4	3.27	1.16	.480	.53	.096	3888	4.43
.095	2	3.53	1.28	.478	.42	.159	4000	4.81
.100	8	3.30	1.31	.431	.50	.097	3698	4.61
.105	8	3.36	1.34	.448	.48	.100	4050	4.70
.110	9	3.36	1.29	.428	.55	.115	4318	4.65
.115	7	3.31	1.27	.392	.58	.120	4099	4.58
.120	22	3.31	1.31	.360	.51	.119	4305	4.62
.125	10	3.37	1.40	.358	.64	.122	4253	4.88
.130	14	3.23	1.29	.262	.54	.138	4402	4.52
.135	8	3.42	1.27	.271	.60	.106	4366	4.69
.140	10	3.31	1.31	.256	.60	.126	4223	4.62
.145	5	3.39	1.30	.291	.48	.131	4005	4.69
.150	2	3.24	1.12	.240	.54	.125	5055	4.36

Table 2
PHOSPHORUS—DEFLECTION
Summary of Test Bar Data—No Steel in Mixture

Deflection in Inches	No. of Test Bars Broken	Average Total Carbon Percent	Average Silicon Percent	Average Phosphorus Percent	Average Manganese Percent	Average Sulphur Percent	Average Transverse Strength	Silicon + Carbon
.085	1	3.69	1.90	.570	.72	.098	2900	5.59
.090	4	3.62	1.84	.595	.67	.104	3135	5.46
.095	5	3.57	1.75	.475	.70	.106	3260	5.32
.100	9	3.59	1.72	.542	.70	.114	3355	5.31
.105	7	3.61	1.72	.465	.66	.125	3209	5.33
.110	12	3.59	1.81	.441	.59	.133	3320	5.40
.115	8	3.43	1.77	.474	.62	.115	3440	5.20
.120	6	3.60	1.73	.442	.63	.130	3375	5.33
.125	4	3.58	1.67	.362	.58	.126	3288	5.25
.130	4	3.59	1.75	.365	.58	.124	3075	5.34

per cent phosphorus. We found that up to .30 phosphorus the steadite (if we can so term the phosphorous rich component) is not the familiar cellular eutectic, but a structureless component somewhat harder than ferrite. From .30 to .50 per cent phosphorus increasing amounts of the structure appear cellular, while above .50 per cent phosphorus nearly all the structure is cellular.

This indicates a series of iron phosphorous solid solutions up to the eutectic composition. This increase in phosphorus is marked by a slight increase in strength, but most notably by a progressive decrease in deflection under ultimate load. Confer Fig. 2 of this discussion. This decrease is rapid around .40 to .50 per cent phosphorus. Machineability seems little affected from .20 to .40 per cent phosphorus, but above .50 per cent phosphorus tool life is materially decreased. Turning to the chart of Prof. Wüst's work, we find a remarkable conformation. Suppose we assume cellular

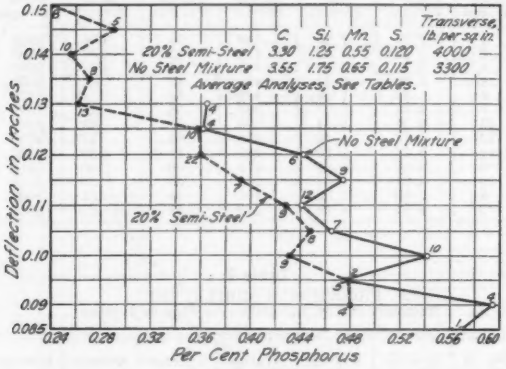

FIG. 2—DATA OF TABLES 1 AND 2 PLOTTED.

steadite as 10 per cent phosphorus and its gravity that of the iron; concepts but slightly at variance with accurate expression. Then for any given phosphorus the eutectic should be given by the formula $C = 4.3\ (1.00 - .10P)$—but it isn't. Up to .30 to .40 per cent phosphorus the curve is much flatter than that demanded by the equation. This checks our observation on structure. I believe the total evidence is sufficient to draw the following conclusions:

(1) Under .30 per cent phosphorus in nearly pearlitic irons we have a series of iron phosphorous solid solutions below 10 per cent phosphorus.

(2) These solutions follow the general laws of physical chemistry, which demand increase in strength and hardness of the component for such a condition.

(3) The position of the eutectic (other elements disregarded) is more logically given by a formula $C = .30 + 4.0 (1.00 - .10P)$.

(4) The eutectic, distinguished by its cellular structure, of lowest melting point, also seems to be harder than the preceding

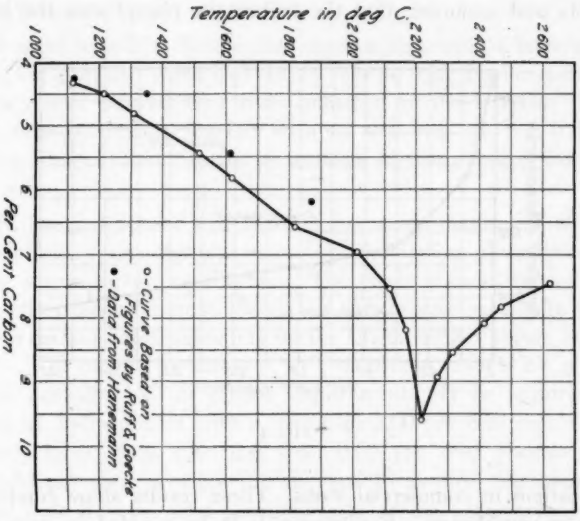

FIG. 3

solid solutions and to arrange itself more effectively between the pearlitic intergranular boundries.

Replying further to Mr. MacKenzie's remarks on page 447, our results on deflection were based on changes in phosphorus and deflection, silicon and carbon constant. This we will show in Tables 1 and 2 appended to this discussion.

It is unfortunate that Mr. MacKenzie did not give more thermal data. Solution saturation of any compounds varies with the temperature (and with pressure, which factor we may disregard for the present). Ruff and Goecke, and also Haneman show that for iron carbon ultimate solubility extends from about the eutectic at 1125 degrees Cent. to nearly 10 per cent at 2200 degrees Cent. Confer Fig. 3 of this discussion. It may be contended that solubility at the eutectic is the important point and for most work this is true.

There is some chance of misinterpreting Mr. MacKenzie's results and assuming that the higher the phosphorus the lower

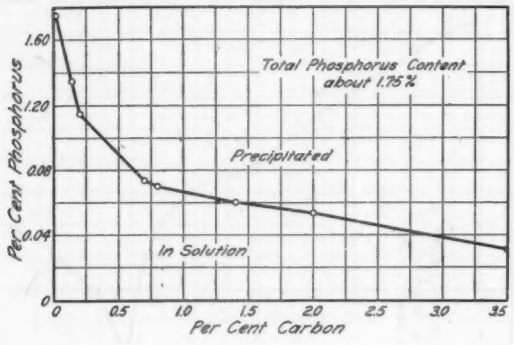

FIG. 4

the carbon in commercial irons. These results show conditions near to equilibrium. Equilibrium is to be avoided by gray iron metallurgists. For example, we get metal of .30 per cent phosphorus with as low as 3.00 to 3.10 per cent carbon, certainly hyspeutectic. Beside solubility equilibrium (if that term is permissible) allow me to remark that we also wish to avoid thermodynamic equilibrium when attempting production of highest grade irons.

Too, let me again emphasize careful balancing the good effects of phosphorus as outlined by Mr. MacKenzie against its bad effect on machineability and on shock (this latter is indicated

in the writer's A. F. A. exchange paper before the 1925 meeting of the Belgian Foundrymen's Association).

Concluding, we again congratulate Mr. MacKenzie on his paper, and sound again the keynote—structural analysis.

AUTHOR'S REPLY TO DISCUSSION

J. T. MacKenzie: I wish to thank Mr. Bolton for his discussion and especially for the tabulation of the results which were the basis of my criticism. The detailed results will be quite useful to me in future work.

I agree with Mr. Bolton that thermal data should have been taken, but previous work had shown that pouring temperature in ordinary iron showed very little influence on the test bar. The work was, therefore, started without the idea of the hypereutectic alloys in mind, so the importance of temperature was not foreseen.

It does not appear that there is any more chance for misinterpretation of the phosphorus-carbon equilibrium than there is of the silicon-carbon equilibrium. The paper shows that with a given phosphorous content, the carbon cannot successfully be held above a certain point depending on the silicon (other things being equal). The capable metallurgist will, of course, control his phosphorus according to his carbon requirement. If he required a carbon of 3.70 per cent with a silicon of 2.00 per cent he should certainly have stock with less than 0.50 per cent phosphorus. It would not seem possible for any one to assume that because he had only 0.50 per cent phosphorus he would necessarily have 3.70 per cent carbon in his castings. If such doubts should arise, a brief glance at Mr. Bolton's results would suffice to dispel them.

The paper is in no sense a brief for phosphorus nor was it the author's intention to show it had any special advantages. Its influence on the mechanical properties are only touched on here and the full discussion of these is left for a subsequent paper.

Continuous Iron Temperature Recording

By H. W. Dietert and W. M. Myler, Jr., Detroit, Mich.

Introduction

The influences of temperature and changes in temperature are the most powerful forces of nature. Practically all manufacturing processes involving changes of property of matter require definite temperatures for the proper completion of such changes. In the metal industry, the accurate measurement and control of temperatures and temperature changes is most important, for the success of a process or the quality of a product is directly dependent upon such controls.

Competition demands that articles be manufactured from materials which have the most desirable properties. This has necessitated in modern industry a scientific control of the working, critical and melting temperatures. It is this latter temperature which is of primary importance in the foundry, both in the non-ferrous and ferrous fields.

In the non-ferrous field there has been great progress made in the determination of the best pouring temperatures and the control and recording of these temperatures. This progress has been furthered by several causes. The comparative ease with which the temperature of many of the non-ferrous metals in the molten state may be measured by direct immersion of thermocouples in the molten metal has been an incentive in this field. The relatively high cost of most non-ferrous castings compared with ferrous castings has been an incentive to keep the scrap loss at the lowest possible minimum.

In the ferrous field there has not been nearly as much progress in temperature control as in the non-ferrous field. There are several reasons for this. One of these is the wider range of temperature at which ferrous metals may be poured and still produce castings which will pass test and inspection. The acceptance of a

*Engineering Dept., U. S. Radiator Corp.

rather high foundry loss as a sort of "necessary evil" has also had much to do with the lack of temperature control of molten iron. Last, but not least, the practical difficulties encountered in the actual measurement of such temperatures have been most vexing problems.

Where foundry men have realized the importance of a proper temperature of molten iron and have given due regard to the control of the cupola to give them the required iron temperature throughout the heat, the actual results secured warrant all the efforts.

Economical mass production which is rapidly entering the foundry field is requiring more of the foundryman's time for thought and managerial directions. Practical working details cannot be under his constant attention. Under the old system of foundry operation he could give personal attention to the numerous details of operation. The new system, though diverting his attention and time, still holds him liable for these details of operation which so often spell disaster if entirely neglected. The modern foundryman needs modern machines both in production and testing. Testing machines are a great aid in furnishing him with reliable figures or charts showing the manner in which the men in the various departments are working their materials.

Scope of Paper

This paper describes a continuous iron temperature recorder attached to the cupola spout which indicates by means of a scale and pointer the temperature of the molten iron at any period of the melt. It also makes a continuous record on a chart of the temperature throughout the heat.

A study of the charts made by this machine enables the foundryman to give specific instructions to the cupola tender so as to produce iron within a definite temperature range. The tender also knows that the results of his efforts are recorded by the temperature recorder, the chart of which may be noted at any time by the manager and will be studied by him the next day.

The use of this temperature recorder is not intended to cast any reflections upon the ability of the foundryman to tell the proper temperature of the iron, but is intended to relieve him from the constant necessity of standing in front of the cupola in order

to know just how it is operating. The devotion of his time to other endeavors, with an occasional inspection of the iron or temperature chart and a study of the complete chart before the next heat and the resulting casting loss has produced a much improved over-all foundry efficiency.

Methods of Measuring Molten Iron Temperatures

The immersion pyrometer which is a popular method of measuring temperature of the non-ferrous metals fails in the practical application for continuous ferrous metal temperature measurement. The principle of the immersion pyrometer requires the immersion of two different kinds of wire into the molten metal. The higher the temperature the greater will be the voltage induced. There are no known elements which will withstand the high temperature of molten cast iron or steel continuously. The short life and high cost of possible pyrometer elements and protecting tubes for occasional immersion in ferrous metals makes this method impractical.

The optical pyrometer which measures temperatures by color comparison appears to be another logical method. This form of pyrometer requires an operator and has not been adapted to the continuous recording field. It is also subjected to personal errors of the operator.

The radiation pyrometer is particularly designed for measurement of exceedingly high temperatures. Its principle of operation is the measurement of the amount of heat radiated from a hot body. This form of pyrometer may be so connected as to give a continuous record of the temperature. After an extended use of this pyrometer it was found unreliable for our purposes. Accurate results were obtainable on heats where the iron ran clean, but on heats where the iron was covered with a scum, for example, slag or graphitic carbon precipitation, the temperature reading of the radiation pyrometer was very high. At the same time the iron would be shown moderately dull by the eye, optical pyrometer and the other two methods, namely, the calorimeter method and the continuous recorder as described later. The amount of heat radiated by molten iron increases whenever it is covered with a dark body such as slag. This accounts for the behavior of the radiation pyrometer on heats of dirty iron.

Another method used to measure the temperature of molten metal is the calorimeter method. This method, while accurate, is only practical for check purposes. The principle involved is the measurement of temperature rise of a known weight of water due to the additions of a known weight of molten metal. From the data thus obtained, the molten metal temperature is computed.

Considerable experimentation with the previously described methods convinced us that actual temperature measurements were impractical. During the course of the previous experiments the idea was conceived that the temperature of gases evolved from the iron should bear a definite relationship to the iron temperature and that an increase or decrease in iron temperature should cause a corresponding change in gas temperature.

The scheme proposed and subsequently worked out and adopted was the suspension of a bare base metal thermocouple shielded from air currents at a fixed distance above the iron stream in the spout of the cupola. The measurement of this gas temperature, furnishes just as satisfactory a control figure as if the actual iron temperature were measured. The remainder of this paper is devoted to the description of the apparatus and methods used and the results obtained.

Description of Continuous Iron Temperature Recorder

The iron temperature recording system consists of two parts, the thermocouple with its protecting hood, which is placed on the cupola spout and the recording mechanism located at a safe distance from the cupola.

In Fig. 1 is shown the thermocouple supported over the cupola spout by the sheet metal hood. The distance from tip of thermocouple to surface of the iron stream is 2 inches. The spout is so constructed as to slag the cupola from the front under continuous cupola operation. The sheet metal hood rests upon the iron frame of the spout. The object of the hood is to form a support for the thermocouple and also to collect the gases from the iron without the intermingling of air.

The details of the hood are shown in Fig. 2. It may be noted that the hood consists of two supporting members and a sheet metal box, one side of which takes the form of an arc to compress the gases and deliver them to the slotted vent.

The manner in which the hood and thermocouple are assembled on top of the cupola spout is shown in the cross sectional view (a) Fig. 3. This view shows only the section of spout in front of the slag bridge block. The iron comes underneath this

FIG. 1—THERMO-COUPLE AND HOOD ATTACHED TO CUPOLA SPOUT

bridge block and travels upward and then flows out over the spout tip. The detail of the spout tip is shown in Fig 3b. As the iron flow is changed from the upward to the horizontal flow, large quantities of gases are given off by the iron. These gases are trapped by the hood and flow out of the vent located at the top of the front wall of the hood. The thermocouple and the gases collected in the hood are protected from air currents by the walls of the hood and sides of the spout. In order to insure

that the spout is lined correctly, the spout template shown in Fig. 3 (c) is used as a gauge.

The assembly of the thermocouple consists of the parts shown in Fig. 3(a). A ⅛ inch nickel chromium-nickel aluminum bare thermocouple projects ⅜ of an inch beyond the lower end of a ¾ inch diameter nickel chromium protecting tube. On the upper end of this tube is fastened a terminal head at which point the thermocouple elements and the asbestos covered compensating leads are connected. The compensating leads carry the electric

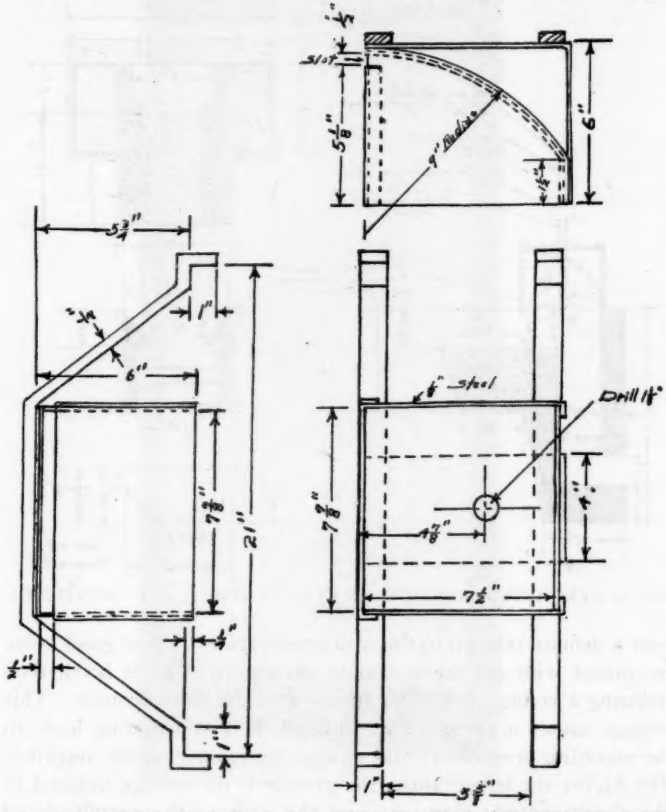

FIG. 2—DETAILS OF THE HOOD USED TO SUPPORT AND PROTECT THERMO-COUPLE OVER THE IRON STREAM

current produced by the thermocouple to the recording mechanism shown in Fig. 4. A clock mechanism pulls the chart underneath the pointer of the instrument and draws a continuous record of the iron temperature throughout the day's heat. The large numbers shown on the chart in the vertical row indicate the time of day and the small numbers shown on the arc lines are the temperature scale.

The operation of the system may be explained briefly by stating that the molten iron gives off gases; the temperature of which

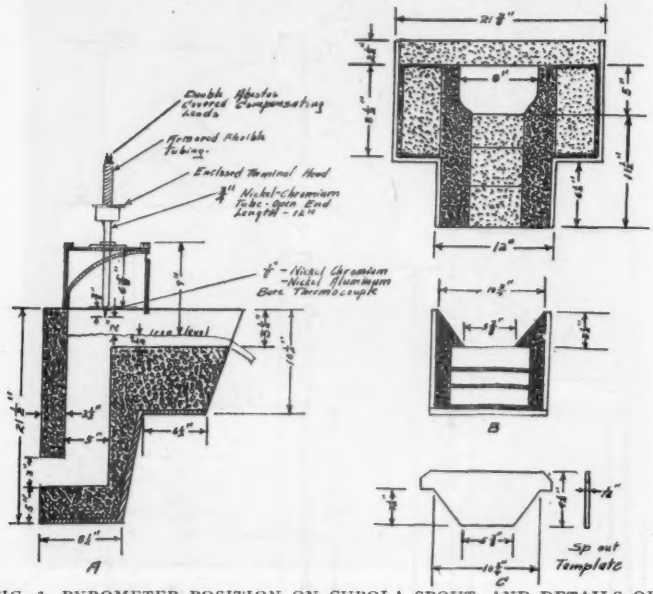

FIG. 3—PYROMETER POSITION ON CUPOLA SPOUT, AND DETAILS OF SPOUT

bear a definite relation to the iron temperature. These gases come in contact with the thermocouple elements under the hood, thus inducing a voltage at the hot junction of the thermocouple. This voltage causes a current flow through the compensating leads to the recording mechanism and swings the pointer of the recorder. The higher the temperature, the greater is the voltage induced in the thermocouple elements and the greater the amplitude of swing of the pointer.

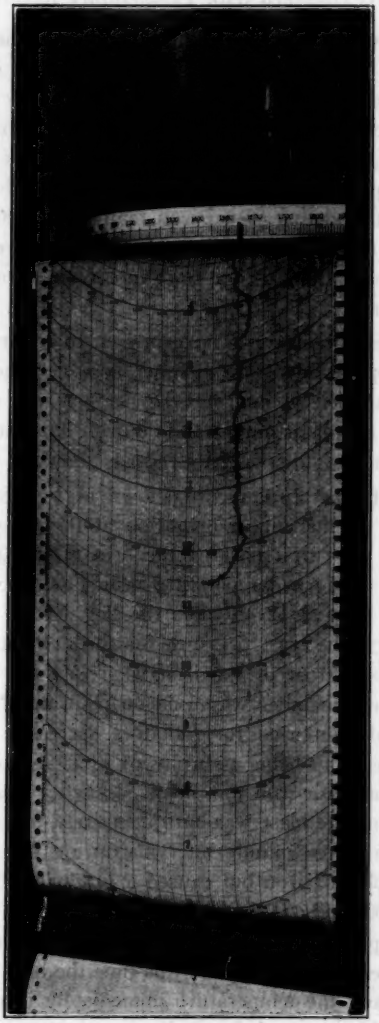

FIG. 4—RECORDING MECHANISM USED TO RECORD THE TEMPERATURE OF THE IRON

Results Obtained with Temperature Recorder

The results obtained by using the records of the temperature recorder prove conclusively that the foundryman is capable of judging whether or not the iron is in a satisfactory pouring condition for his class of work. However, the temperature records show that the judging of iron temperature by the eye gives only a vague conception of what really occurs throughout the heat. We have also found that visual iron temperature comparison between cupolas of different locations or plants is unreliable for accurate comparison. This is due to difference in surroundings and analysis of iron.

The temperature records have proven of great value to improve cupola operations. The manner in which the temperature recorder was applied to improve the performance of a continuously operated cupola at our plant D is well illustrated in the following by an analysis of the chart records shown.

The iron temperature record shown in Fig. 5A is a representative chart of the cupola operation at the time the recorder was installed. The first part of the heat from 12 to 1 o'clock shows a fairly uniform temperature near 1400 degrees with the exception of a drop at 12:45 when the slag started to run out of the slag spout. The blast pressure for the first part of the heat was ten ounces. Most of the iron was used for pouring radiators, while the remainder was used on plate and boiler sections. The amount of iron used for radiators decreased quickly after 1:30 P. M., the result being a surplus of iron. From 1:30 to 2:40 P. M. the demand for iron was small. In order to slow down the rate of iron flow the blast was cut off entirely for about 15 to 30 seconds at five to ten minute intervals during this period. This avoided a surplus of iron but caused a gradual drop in temperature from 1400 to 1200 degrees. At 2:40 P. M. all the boiler molds were up and the boilers were poured off as fast as the cupola could deliver the iron. At this time the blast was increased to 16 ounces and the temperature immediately increased to 1300 degrees but did not reach its earlier maximum temperature of 1400 degrees for the remaining portion of the heat.

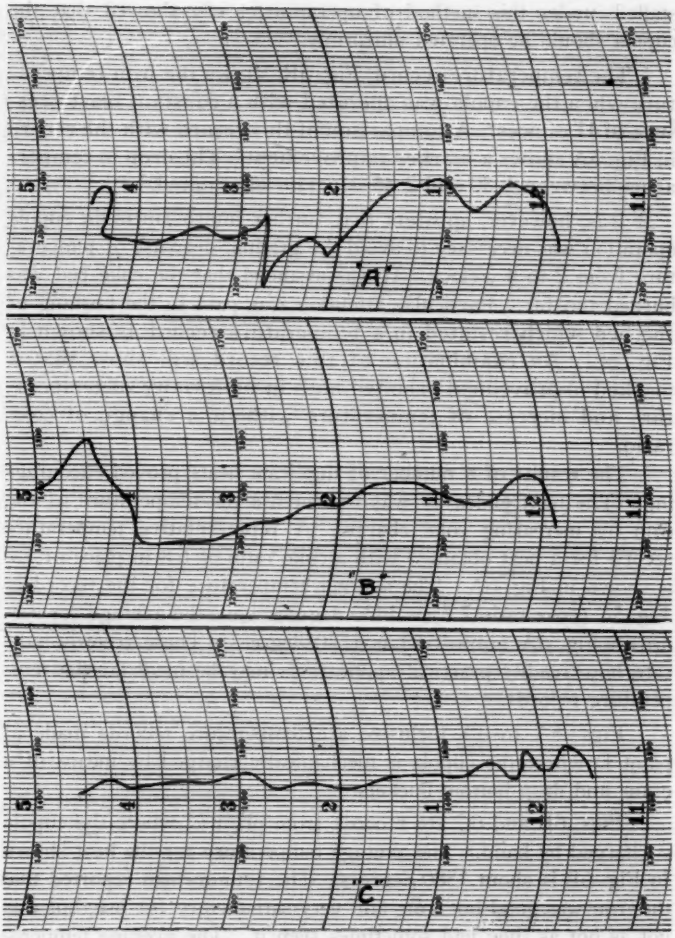

FIG. 5 (A)—TEMPERATURE CHART SHOWING ORIGINAL METHODS OF OPERATION AT PLANT D. (B)—TEMPERATURE CHART SHOWING IMPROVEMENT DUE TO USE OF A UNIFORM BLAST PRESSURE AND OPERATION AT PLANT D. (C)—TEMPERATURE CHART SHOWING IMPROVEMENT DUE TO UNIFORM BLAST PRESSURE, OPERATION AND MORE CAREFUL BURNING OF THE BED

Several days of operating the cupola with the recorder installed, under this method of operation clearly showed that the cupola should be operated uniformly.

The temperature record, Fig. 5B, shows the iron temperature when the cupola was operated with a constant blast pressure of 11 ounces. A comparison of this record with the record in Fig. 5A shows a marked improvement. The drop in temperature between 1:30 and 2:45 is partly eliminated.

It was, however, apparent that further improvement in cupola operation was necessary to avoid the gradual decrease of temperature from 2 to 4 o'clock. It was assumed that the coke bed was burned too far. Particular attention was paid to the burning of the bed which resulted in a temperature record as shown in Fig. 5C. An examination of this record will show that a marked improvement resulted both in uniformity of temperature and increase of temperature without a change of coke ratio.

The results of a number of duplicate heats proved encouraging. The next endeavor was to increase the temperature of the iron by increasing coke charge. A representative temperature record for a heat obtained with a coke ratio of 6.8 in place of 7.7 is shown in Fig. 6A. The average temperature for the record in Fig. 5C (coke ratio 7.7) is 1430 degrees while the average for record in Fig. 6A (ratio 6.8) is 1570 degrees. These records indicate how readily practical applications may be made of the temperature records.

Figs. 5A to 6A inclusive are temperature records made at plant D where the cupola is mechanically charged by means of a crane and drop bottom buckets.

Figs. 6B and 6C are records from plant N where the cupola is charged by hand. The average temperature for the heat shown in Fig. 6B is about 1580 degrees. The foundryman reported that the iron was good hot iron, and very satisfactory for use, but was not as hot as they had sometimes seen it. The average temperature of the heat of Fig. 6C is about 1680 degrees. The foundryman reported that the iron was very hot and that the cooler pipe section workers were cooling their iron before pouring. A number of these sections were lost that day due to burned out chaplets.

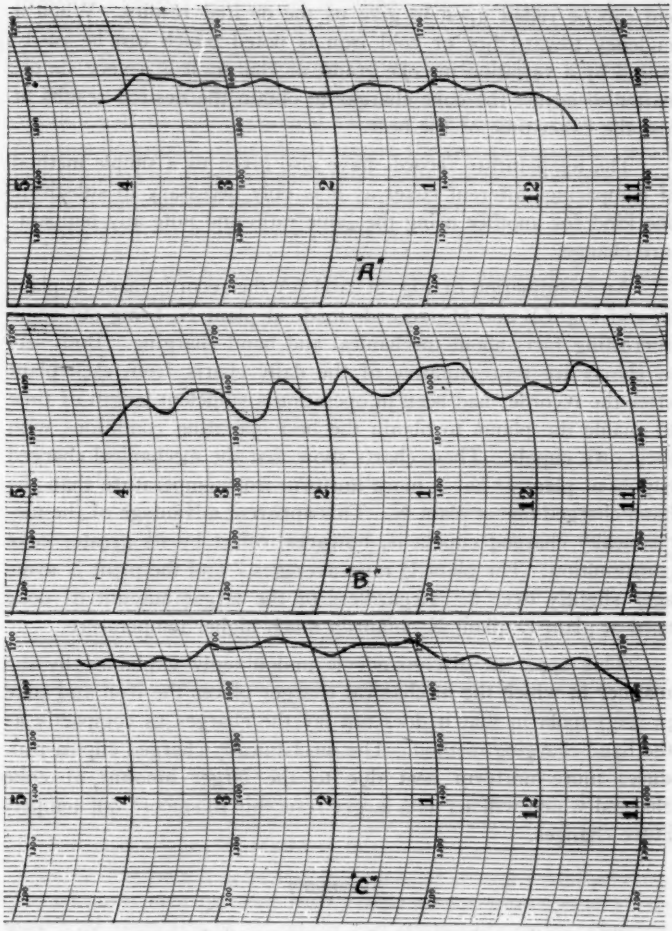

FIG. 6 (A)—TEMPERATURE CHART AT PLANT D SHOWING THE INCREASE IN TEMPERATURE DUE TO INCREASING COKE CHARGE. (B)—TEMPERATURE CHART OF PLANT N, SHOWING A VERY SATISFACTORY HEAT. (C)—TEMPERATURE CHART OF PLANT N, SHOWING A HEAT AT WHICH THE IRON CAME HOTTER THAN DESIRED

The consistent agreement between the temperature records and pouring results has shown us conclusively that the recording system can be relied upon to give us the desired results. When a tendency toward hot or cold iron is noted which can be easily caused by a variation in coke grade, or charge, it is a very simple matter to adjust the coke charges to obtain the desired results at just the exact time of the heat.

The temperature records have also given us a simple method of comparing different cokes as it is only necessary to substitute one kind for another using the same ratio and note any temperature change.

An examination of Fig. 5C and 6A the records made at plant D, and Fig. 6B and 6C, records made at plant N, bring out some interesting facts about mechanical and hand charging. Both sets of charts are representative of the daily charts from each plant after the recorder had been in operation a sufficient length of time to enable the plants to obtain the best operating conditions with their own cupola. These charts show that the mechanical charged cupola at plant D has a more uniform iron temperature than the hand charged one at plant N. This apparent advantage of the mechanically charged cupola is, however, offset by its greater coke consumption. The plant D ratio averages 7 and the plant N averages slightly over 8. Regardless of the larger amount of coke used at plant D, plant N obtains a much higher temperature.

This apparent discrepancy is undoubtedly explained by the manner in which the mechanical charger places the iron and coke in the cupola in that it does not lay the charges as compactly as the hand charging method. The mechanically charged cupola produces more uniform heat due to the larger amount of coke charged which will act as a larger reservoir to smooth out temperature changes.

Summary

This is the only iron temperature control system with which we have experimented that has given us practical and reliable results, and also at all times has checked the opinions of experienced foundrymen.

The system was designed with the idea of affording us a practical foundry control of a cupola and a record of its performance.

From a practical operating standpoint the exact temperature is immaterial. A machine which would give such information would be of no more practical value in the foundry than the system just described. The object sought for was an apparatus which would enable us to record conditions in such a way that when once the most satisfactory pouring range had been determined, it would be possible to duplicate these conditions at will.

Although the above described system is undoubtedly capable of being improved, it is nevertheless satisfactorily answering our need.

DISCUSSION

CHAIRMAN L. L. ANTHES: We are very much indebted to Mr. Dietert. He is one of our youngest men and one of our most aggressive men. He has started a new departure in cupola practice and, to my mind, this is one of the brightest papers on cupola practice I have heard for some years. I wish there were a lot of foundry foremen here who could get up and ask questions. Of course, Mr. Dietert made some points that were open to argument and I expect he is going to have some argument on those points, so I will immediately open the meeting to discussion.

A MEMBER: Mr. Dietert said that constant pressure was necessary in the cupola in order to obtain uniformity in temperature. Now, suppose we get some coke in the tuyeres; your pressure may be quite different from what you started with when you did not have any coke in the tuyeres, and the velocity of the air may be different, but the total volume may be the same, and after all it is the amount of air and the amount of coke which will determine the temperature. I wonder what Mr. Dietert has to say in regard to this?

H. W. DIETERT: I grant that the volume of air is the principal thing. Our apparatus does not lend itself readily to the measurement of the number of cubic feet of air on the iron temperature curve. However, we are working on that so that we can put the cubic feet of air going into the cupola right on the iron temperature curve. We have a volume meter right by the cupola to watch it. If we have those curves on different charts, the men in the foundry do not have the time to put them together and figure them out. That is office work. If you can

get a machine that will put two or three curves on one chart so you can see them at a glance, you have solved the problem and that is the end towards which we are working. It is a rather new proposition to us, and probably to anyone. We solved one cupola difficulty by freeing our tuyeres from slag so that on this particular installation our tuyeres are absolutely free from slag. If your tuyeres slag up at the end of the heat, you have a poor cupola practice.

DR. R. MOLDENKE: I do not like to throw cold water on Mr. Dietert at all because he is struggling very hard to work something out, but I do think Mr. Dietert is working on one very special line of work. I think you are working with radiator work, are you not?

MR. DIETERT: Radiator plates and boiler sections.

DR. MOLDENKE: In that work it is extremely necessary to have very high temperatures all the time, otherwise, your percentage of loss goes up at once. You are working with high silicon and soft iron, so that your philosophy of a cupola process is entirely at variance with the regular practice, because you work with different amounts and volumes. I would rather fear to have this to apply to ordinary foundry practice. You are working with temperatures. The fact that you reduce the volume is a very bad thing in regular foundry practice. I do not feel that I ought to condemn what you say, but I want to say that you are working on a very special corner of the foundry industry and what you have brought up, in my mind, is not applicable to the rest of the foundry so much, perhaps, as you think. I wish you luck, just the same.

CHAIRMAN ANTHES: The fact is that there is quite a variation between boiler sections and radiator sections.

DR. MOLDENKE: There is a variation, true enough, but you do not sometimes see what is inside of a boiler section, you do not machine it.

A MEMBER: What is the thickness of a boiler section?

H. W. DIETERT: Five-sixteenths, and a radiator section is five-thirty-seconds. I wish we did not have to machine boiler sections, but we have some machining and it is quite a problem to get the iron so that it will machine. There cannot be a chatter hole, otherwise, we have a leak. The weight of a section runs from 235 pounds to a radiator to boiler sections weighing 500 pounds. We are not only hitting loss, we are hitting cost. We save in coke, but we do not believe in saving coke to get dull iron.

G. K. ELLIOTT: I was very much interested in this paper. I think it opens up a very fertile field. Before I could discuss it further, I would like to have Mr. Dietert tell us what the actual temperatures of the iron are. I cannot think of iron in the terms he uses; that is, you say, I think, 1700 was pretty hot iron; what was that iron actually?

H. W. DIETERT: 2700 degrees Fahr. We try to operate at 2600 degrees. We do not run at 1700 on our scale.

G. K. ELLIOTT: I found out in making pressure castings that watching the temperature is not of a great deal of importance. If you have cold iron, you have a lot of leakers, we call it. Hot iron does not bother us much if the molding is suitable for hot metal; in other words, the hotter the iron if the mold is built right, as a general thing, the better the casting. I found out that 2,600 degrees Fahr. is a very satisfactory temperature for cupola iron for that type of work. Electric furnace iron, such as we make runs between 2700 and 2800 degrees. I am anxious to hear what the temperatures were. I might say that we measured a great many temperatures and we used the optical method and had to have a man on the job all the time making the readings, but it worked out very satisfactorily. It took one man's full time but it was well worth his time and what we learned from his observations will be of lasting benefit to us.

CHAIRMAN ANTHES: I think Dr. Moldenke wants to touch on another point, and that is that the temperature of iron has to do with quality. Do you want to say anything about that, Doctor?

DR. MOLDENKE: I have always, in my own experience, tried to melt as hot as you can melt, and pour it hot if the sand will stand it. If the sand can stand it, all the better, but unless your gates are all right, you are apt, with very hot iron, to get into more trouble than you are with cold iron, because the gates may freeze off and when the iron is liquid in the mold and you cannot get any more from the basin, you get shrinkage. But the ordinary rule is to melt as hot as you can melt it. What Mr. Dietert wrote is exceedingly interesting, but I feel that it applies to one end of the foundry business and is not quite applicable to the other, because I know that I have achieved very good results by using the normal regular way of operating with volume regulation and not pressure.

R. CRAWFORD: I would like to have Mr. Dietert explain about his mechanical charged cupola as compared with hand charging.

H. W. DIETERT: Our mechanical charger is not right now up to date; it is one of the older type. It has the drop leaf bucket on it; the bucket will drop this way and next time the fellow will turn it this way. Now we put the coke at the bottom and in regular order put the iron on top of the coke and the limestone. The bucket is hoisted up into the charging platform, run into the cupola and down and then the charge is dropped. There is a more improved type of bucket on the market, but we hang on to the old one because we find it more durable than some of the newer ones.

The cost for charging is not any lower than in some of the hand charging plants because in hand charging the method has all been worked out to a high degree of efficiency.

R. F. HARRINGTON: I think Mr. Dietert is to be commended for this paper of his. His work ought to result in the more frequent application of mechanical means of measuring temperature. It may not be, in the case of many foundries, quite so important as it is in his and in our particular foundry. Take, for example, the foundries operating air furnaces or malleable furnaces, if they have one of these recording type of pyrometers on their spout, they can certainly save on their fuel bill. Our fuel bill has been reduced considerably by the operation of the optical pyrometer as applied to the temperature of the metals running from the spout. It means that we can allow our furnace to coast along and save a few pounds of coal, which means a great deal to us in our plant. We are operating two pyrometers every day all during the pouring period, and I believe that we can probably credit to the extended use of optical pyrometers a marked reduction in the loss from cracking castings in the chipping room. I think in one case where a study was made of castings measuring 40 inches in length, about 40 inches in diameter and about an inch in cross section, we found after studying the condition of those castings after machining an eighth of an inch off the surface, that unless those particular castings were poured at 2600 degrees or better, we could be sure that there would be a defect immediately underneath the skin; in other words, it seemed to be only a matter of 50 degrees between a good casting and a poor one so far as perfect effect immediately under the skin goes. If we increase the section of that casting to an inch and a half, the 2550 degree temperature was perfectly satisfactory, but if that casting were one inch thick only, and 40 inches long, it was necessary to pour that casting at 2600 degrees or better to get a casting free from defect after machining the inside and outside surface.

DR. MOLDENKE: I cannot help but still caution you on this whole subject, because one thing has been left out, and that is this was good clean iron, unoxidized iron; you were working with high silicons, and probably had unoxidized metal; but suppose you had oxidized metal, your freezing point would be much higher and you might get fearfully stung. I have seen an example of that in one of the large concerns in the east, where they have optical pyrometers used all the time and will not pour under a certain temperature. I saw their practice carried on day after day. Then they ran into some bad pig iron and the consequence was that they got their good temperatures, but when they poured on the floor, the first castings were good, the next just passed and the last were rotten. With good pig iron it was all right. I would not like to see a generalization applied to every case.

R. F. HARRINGTONS I am glad that Dr. Moldenke has brought up that point because it certainly is very important. I have in mind this particular case I have mentioned. We go further than taking the initial temperature, for, as he says, we might get terrible results if we only

considered the initial temperature at which the iron left the spout. We check the first three or four castings, the fifth, the eighth and tenth, and we soon have a definite idea as to the life of that metal, and we use the stop watch in pouring, which gives us a definite idea as to the rapidity with which the mold takes the iron. If it is badly oxidized, we know by the stop watch method that it is or is not oxidized.

H. W. DIETERT: Dr. Moldenke's experience was in our Dunkirk plant, and that is where we found out what kind of pyrometer to use. We had both radiation and optical pyrometers and the iron temperature as shown by the optical pyrometer is not the true iron temperature. Of course, the freezing is different and at this particular plant the iron was badly oxidized, it had the right temperature, but the whole thing was that it was not all pig iron, it was part of a cupola operation and we were using a de-oxidizer at this particular plant. We could measure the temperature all we wanted to measure it, but we never could get by unless we corrected the iron condition. It only shows that we cannot be too careful.

The Electric Melting of Cast Iron

By George E. Lamb,* Hoquiam, Wash.

The electric furnace has established itself as a steel melting medium, will it succeed as an iron melter? From a metallurgical standpoint it is far superior to the cupola for it can use practically any material and through refining or alloying produce a high grade of metal. From an economic standpoint it is usually more costly than the cupola. In certain localities, however, due to the cost of suitable materials for the cupola the electric furnace can compete disregarding entirely the better quality of iron produced.

In the Pacific Northwest the prices of new materials are, due to freight rates, much higher than in the East. Pig iron costs $35.00 per ton and coke about the same. Both of these materials must be brought either by water from the Atlantic Seaboard or by rail a considerable distance. Scrap on the other hand is cheap. Chilled car wheels, usually rejected ones, can be bought from the logging companies at $5.00 per ton and a better grade of machinery iron from the lumber mills at from $7.00 to $12.00 a ton. The low scrap price is caused by an over supply of iron due to the purchases of machinery in the East without any corresponding movement back.

Electric power is reasonable in price. The local power company's tariff applicable to electric furnace power supplied at 2200 volts, three phase is $0.0125 per kilowatt hour or $1.33 per kilowatt demanded for the highest fifteen-minute interval during a month. The highest charge figured by these rates is billed.

Labor for operating an electric furnace or for other foundry work must largely be trained in the shop. Turnover, however, is small so there is little difficulty in keeping a crew. Melters rates vary from $0.75 to $1.00 per hour.

The Lamb Machine Company, Hoquiam, Washington, has been operating an electric steel furnace since June 24, 1919 and

*Superintendent. Lamb Machine Co.

since April 12, 1920, has been using this same furnace for part of the iron required in their business. The work done by this shop consists of steel castings for the lumber industry, usually thin section castings under 100 pounds weight, and grey iron castings for practically every class of work, grate bars, sewer rings, pistons, piston rings, brake shoes and machine frames. The amount of business done is subject to heavy fluctuations. For this reason it is necessary to have the foundry so organized that it can handle any volume of either metal economically and still give quick service.

Melting Equipment

The electric furnace is rated at 3000 pounds capacity. It has been lined down so as to carry a 2000 pounds normal charge. Electric current is stepped down from 2200 volts to either 110 or 80 volts by two oil cooled, 500 K. V. A. transformers connected in open delta. Water cooled copper tube reactance coils set in concrete blocks are used to steady the power input. The voltage regulation is obtained by a special voltage regulator. On the instrument board there are three ammeters, a volt meter, kilowatt hour meter, recording fifteen minute interval demand meter, overload relays and three lights connected between a common ground on the bath and each electrode. These lamps indicate the voltage drop at the arc and if an electrode should get down in the bath or on the charge the corresponding lamp will go out indicating that that electrode should be raised. The electrodes are 5 and ⅛ inch graphite and are manually operated. An acid lining is now used consisting of silica brick walls and roof and a bottom made of silica sand with a binder rammed in place. The shape of the bottom has been found very important in making steel and iron in the same furnace. It should be so shaped that every part can be reached with a ravel and scraped clean. Any ledge in front of the charging door will make it difficult to get material out of the furnace after it has been emptied. The charging door is opposite the tap hole. The shell of the furnace is 6 feet 6 inches by 8 feet lined down to a chamber 30 by 50 inches. Heat insulating brick are used against the walls and have been found economical in conserving heat and in reducing spalling of

the silica bricks during a shut down period. The roof is made of standard wedge shaped bricks laid in a square frame which is easily removable. Cooling rings have been used around the electrode but they were of poor design and owing to their weight caved the roof excessively and have been removed. Plates are kept tight around the electrodes on top of the roof to stop all circulation through the electrode poles. The holes themselves are kept in shape by using a high temperature cement. Charging door and tilting mechanism are hydraulically operated and since the hose connections have been removed from all joints and flexible pipe fittings put in their place they have given no trouble. The furnace can be tilted back 15 degrees and forward 35 degrees. In the back position the bottom can easily be raveled and slagging is facilitated by tipping back until the metal is at the charging door level. A bath 10 inches deep is maintained.

The cupola is a No. 2-A Whiting. Material is elevated to the charging floor by elevator and hand charged.

Method of Melting Iron in Furnace

The usual charge consists of one ton of car wheels broken under a drop until they are easily handled by hand. The largest pieces are first charged into the furnace followed by the smaller much as a macadam road would be built. This method has been found to give the best electrical contact which with this class of scrap or nearly any other kind of iron scrap is usually difficult to maintain. If no small pieces are available broken pieces of electrode are used to fill the void between the large pieces. The voltage is set at 100 volts and the furnace started. Since the iron is usually melted following a steel heat the charge will melt rapidly. By keeping the demand at 300 KWH per hour it is possible to have the charge melted in one hour and thirty minutes. Usually it is difficult to maintain a very high demand at first owing to the poor contact. Broken electrodes or coke thrown on the charge will remedy this condition. When the heat is charged before the noon hour it is usually allowed to soak until one o'clock. This operation is found to decrease the time the current is on.

After a bath has formed under the electrodes there will still be heavy current fluctuations. To remedy this a silica sand and lime slag may be put around each electrode or in case it is desired to carburize during melting a small amount of lime only placed beside each electrode will do the work without injuring the lining.

When the charge is melted it is then heated over the desired pouring temperature, the furnace is tilted back and all slag removed. It is necessary to have a clean bath to get carbon into the iron. When the bath has been cleaned carbon raising graphite is thrown onto the bath, the furnace closed tight and power put on. The bath is stirred with a green wood pole after each addition of graphite. If the iron is to be machined it is necessary to raise the silicon as well as the carbon. The usual total carbon and silicon for the best iron is 6 per cent. In order to get the carbon over three per cent it is necessary to reslag the bath and repeat the addition of graphite. This second addition will usually give a carbon content of 3.25 to 3.40 per cent, only once have we had over 3.50 per cent. The usual time between additions of graphite is 25 minutes. The silicon is added as ferro-silicon. As soon as the silicon is melted the bottom is scraped to dislodge any adhering material and the bath is skimmed clean. A little old foundry sand thrown on the bath will make a slag which will hold the loose graphite together so that it can easily be drawn off. If the current is to be kept on during pouring a silica sand and lime slag is put on to steady the arcs. Immediately after the heat has been poured the furnace is tilted back and ***the bottom scraped clean of all loose material.*** It has been found that although all graphite is removed before pouring there still remains in the furnace some carbon bearing material.

Variations in Practice Tried

Many different methods of making machinable cast iron from the car wheel scrap which is low in both carbon and silicon have been tried and further experiments are contemplated. When the iron was first made in the furnace either a good grade of machinery scrap high in carbon and silicon was used in connection with a small amount of pig iron or a lot of pig iron with about

an equal amount of the car wheel scrap. It was found that iron having the same carbon and silicon content as cupola iron would be much harder so the desired carbon silicon content was set at 6 per cent though seldom over 5.50 per cent total was obtained. The large percentage of pig necessary to obtain this analysis made it costly so carburization was attempted. Cupola coke ground to about pea size was first used but little carbon could be introduced unless the bath was slagged a number of times and much stirring done. It is probable that the difficulty was due to the high ash content about 13 per cent, of the coke used. Various methods of charging the coke were tried, first the coke was put on the bottom of the furnace. This gave only fair results and there was danger of coke sticking in the soft bottom of the furnace. Next steel plate was put over the bottom of the furnace with coke on top of this. The carburization was about the same but more silicon had to be added and the effects of the carbon on the following steel heat seemed no better so the practice of charging coke with the charge was discontinued and since no carbon has been charged before the heat is melted except lumps to assist in making contact.

Silicon also has been experimented with. The first method of introducing it was to charge it with the iron. This appeared to give considerable loss and was also believed to retard the absorption of carbon so was continued and charging near the end of the heat tried. Silicon charged on a clean bath after slagging resulted in a large loss but when charged with a carbon addition the loss appeared less so this was adopted. The amount of ferro-silicon necessary is considerable so other sources were tried but as yet no success has been had though further experiments will be carried on. An acid slag with plenty of coke to assist silicon reduction was tried but very slow reduction was obtained. Silicon carbide was tried and good carburization obtained but no silicon. High silicon pig iron is a good source giving very little loss but it costs more than the ferro-silicon.

Eighty volts has been tried during the melting period but only made electrical contact more difficult to maintain. It was also tried after the charge was melted but the resulting carburization was all at the expense of the electrodes which are more expensive than the graphite used.

Various practices have been tried to keep down the carbon in following steel heats. At first ore was use on the following steel heat. Any foundryman making steel knows the effect of using great quantities of ore, a heavy slag that must be removed, a bath difficult to kill requiring more alloys than one with some residual manganese in it. The ore was discontinued as soon as it was found that by thoroughly scraping the bottom the carbon trouble could be eliminated. Steel plate was put next to the bottom as mentioned before and at one time following the iron heat ore was sprinkled over the bottom but none of the methods gave the results obtained by a good scraping. It was thought that by running three or four iron heats in succession it might be possible to get out a large quantity of iron with only one steel heat in which there would be danger of high carbon. The result usually was that the following carbon heat was three times as high in carbon as it would have been after one heat so this was discontinued.

Observations

When iron was first made in the electric furnace at this plant the method of melting, the charge and other matters pertaining to the metal were left to the melter operating the furnace. As a result each melter made his iron differently with different results. In the accompanying tables are given the results of these different methods as complete as they were recorded on the melting report.

The first heat was made April 12, 1920. On this heat no complete report was made. The first real information obtainable is on a series of iron heats run a year later. At this time trouble was being experienced with hard castings. The charge, the molds, the shake-out, and the pouring were similar to cupola practice yet the resulting casting were harder.

Annealing was tried and the castings were softened to 30 Scleroscope hardness.

Table 1

In 1923 the reports are much more complete (Table 1). Heats No. 524 to 542, Table 1, are typical heats at this time.

Table 1.

Heat No.	Material[1]	Charge—Pounds						Coke Pounds	Silica Sand Pounds	Lime Pounds	Iron Ore Pounds	Time Hours	KWH	Analysis	
		Scrap Iron[2]			Fe Si	Fe Mn	Total							C Percent	Mn Percent
		No. 1	No. 3	No. 5											
524	CS				12	11	2052					4.00	1280	0.15	0.88
525	C1	1500		1500			3000					2.30	800		
526	CS				10	16	2056				30	4.35	1520	0.18	1.07
527	CS				10	16	2056				30	2.30	960	0.21	0.85
528	CS				10	14	2054				30	3.50	1440	0.16	0.74
529	C1	2000		1000	15	15	3030					2.30	640		
530	CS*				10	16	2176				150	5.10	1600	0.18	0.63
531	CS				10	13	2073				50	2.35	880	0.23	0.85
532	CS				10	15	2060				35	3.50	1280	0.22	1.13
540	C1	2000		1000	20	20	3040					2.10	640		
541	CS				10	16	2101				75	3.45	1360	0.18	1.19
542	CS				10	17	2067				40	2.45	1040	0.20	.91
148	CS				7	14	2321	5	15	5	35	5.00	1120	0.18	0.61
149	C1		1180	320	35	15	1550	40	10	30		2.05	480		
150	CS				6	20	2026	5	20	15	40	4.15	1120	0.25	0.61
151	CS				9	27	2736	5	20	5	40	4.40	1200	0.28	0.52
152	CS				6	16	2222	3	20	5	40	4.55	1360	0.18	0.44
200	CS				9	38	3047	5	20	10	10	5.35	1360		
201	CS				6	18	1974	5	30	10	75	5.45	1440	0.24	0.46
202	C1		1100	400	30	15	1545	30	30	10		2.05	480		
203	Alloy Steel														
204	C1		2400		60	28	2488	30	20	5		2.30	640		
205	C1		1600		30	15	1645	30	30			3.40	880		
206	CS				7	31	2438	5	20	5	20	4.05	960	0.24	0.68
207	C1		1500		40	15	1555	30	30	5		2.00	560		
208	CS				8	32	2440	5	20		75	5.20	1200	0.216	0.68
209	C1		2360	440	70	30	2900	30	30			4.20	960		
210	CS				9	42	3051	5	20	5	35	5.10	1360	0.20	0.60

[1]CS indicates a steel heat. C1 indicates a cast iron heat.
*Slagged off.
[2]* Scrap Iron No. 1—Machinery Scrap.
Scrap Iron No. 2—Auto C linder Scrap.
Scrap Iron No. 3—Chilled Car Wheel.
Scrap Iron No. 4—Foundry Returns.
Scrap Iron No. 5—Pig Iron 3.00% Si.
Scrap Iron No. 6—Pig Iron 3.50% Si.

This iron was observed as being solid, clean and easily machinable. The pouring temperature was judged about the same as cupola iron. A year later the same melter made heats 148 to 210. This iron was solid and clean but was hard to machine.

Usually it is not found advisable to run more than one iron heat at a time or an iron heat on a cold furnace but heats 200 to 210 show that it is possible to do both these things if every precaution against high carbon in the following steel heats have been taken.

In melting the heats in Table 1 the entire charge was put in the furnace at the start. The coke was put on the bottom or it was shoveled in with the charge. When the bath was melted a slag was put on.

Table 2

Table 2 gives the results of two other melters. The melter making heats 994 to 5 had very little trouble and produced a fair grade of iron. He, however, had pig iron to use with his scrap. The melter making heats 69 to 89 had trouble with high carbon on following steel heats, his iron was cold and hard.

It was following these melters that the furnace was put in charge of an inexperienced man under the supervision of the foundry superintendent.

Table 3

The first heat, Table 3, No. 251, was made according to the method used by the previous melter. This heat was too hard for machinery castings. On the next iron heat the silicon was not added until the last of the heat. This was done believing that silicon retarded the absorption of carbon. The results indicated that this was true although carefully conducted experiments by the Bureau of Mines have indicated that silicon has no effect on the absorption of carbon.

Heat 255 to 259 were operated at 80 volts. In these heats there is a slight pickup of carbon apparent in the iron and considerable pickup in steel. The carbon pickup in iron was not suffi-

Table No. 2

Heat No.	Material	Charge			Pounds									Analysis		
		Scrap Iron[1]			Fe-Si	Fe-Mn	Total	Coke Pounds	Silica Sand Pounds	Lime Pounds	Iron Pounds Ore	Time Hours	KWH	C Percent	Mn Percent	Si Percent
		No. 3	No. 4	No. 5												
994	C1	1230		810	45	12	2097	5	10	3		2.45	480			
995	CS				11	13	2124	10	10	4	110	3.50	1040	0.23	0.67	0.30
3	CS				10	20	2130	12	10	4	40	3.40	1040	0.22	0.59	0.23
4	C1	1390		710	50	12	2162	3	3	7		2.30	480			
5	CS				8	18	2126	12	10	4	90	3.35	1040	0.26	0.68	0.32
69	CS				3	25	2328	7	15	5		3.40	960	0.12	0.62	0.20
70	C1	2505	595		65	20	3185			5		2.55	640			
71	CS					30	3030	5	15	5		4.00	1100	0.27	0.85	0.22
87	CS					24	2424	5	15	5		3.10	800	0.22	0.54	
88	C1	2200	130		100	30	3630	100	10	20		4.45	1360			
89	CS				15	35	2635	10	50	15	250	5.20	1280	0.33	0.82	

[1]See Table 1 for scrap iron classification.

cient to warrant the extra electrode consumption. In heat No. 268 graphite made from ground electrodes was used in place of a portion of the usual coke. Comparing this with the previous heat there appears to be a very good carburization due to the graphite. Heat 270 shows similar results.

The first heat, No. 251, besides being low in carbon was low in silicon. This was remedied by adding more ferro-silicon. From the results of heat 253 a very heavy loss is apparent. Heat 256 shows much better results in this respect. It appears in operating at 80 volts there is less loss of silicon than with 110 volts. Since this loss was heavy the different methods were tried to conserve the silicon.

In heats 264 and 268 the silicon was added to the bath of iron after all slag and coke had been removed. This gave poor results. G. K. Elliott in his report* before the American Foundrymen's Association showed that silicon could be added to the bath by reduction from an acid slag. In heats 270 and 272 this method was tried. It is apparent that there is some pickup but for some reason the pickup was not as large as should be expected. Heats 335 to 369 were made after the process had been fairly well developed.

Heats 335 to 341 were made in the furnace just before it was relined. It will be noticed that the carbon pickup in carbon steel heats was very slight. From 342 to 369 are the first heats on the new lining. A heavy carbon pickup at first troubled the melter, the only way in which this can be accounted for is that the bath was too deep to be raveled after the heat had been poured. As a result some carbon bearing material remained in the furnace. At heat 359 the bottom was changed and thereafter little trouble with carbon was had.

In this series of heats further experiments in introducing silicon were tried. Silicon carbide was used. This material was added to the bath after it had been slagged clean and was fairly hot. Good carburization was obtained but practically no silicon was added to the bath.

*G. K. Elliott, Trans. A. F. A., Vol. 31, p. 139, 1924.

Table No. 3

Heat No.	Material	Charge—Pounds							Coke Pounds	Silica Sand Pounds	Lime Pounds	Iron Ore Pounds	Time Hours	Kilo Watt Hours	Analysis				NOTES
		Scrap Iron[1]			Steel	Fe-Si	Fe-Mn	Total							CC	GC	Si	Mn	
		2	3	4											Percent				
251	C1		1050	580	630	20		2280	50				4.50	1120	0.68	1.45	1.60	0.61	Furnace idle 5 days previously
252	CS				2105	6	21	2132				40	4.35	1200	0.24			0.55	Ore added at first of heat
253	C1	230	2970			150	18	3368	25				5.30	1040	0.85	2.01	1.99	0.78	Silicon added 30 minutes before poured
254		Alloy Steel										42			No Carbon		Pick Up	Apparent	
255	CS				2725	8	30	2763					6.30	1520	0.33			0.72	Operating at 80 volts caused Carbon
256	C1		1175	660		90	11	1936	25	50			3.50	800		2.12	3.10		Operating at 80 volts
257	CS				2061	6	20	2087				30	4.50	1040	0.38			0.84	Operating at 80 volts Ore after control
258	C1		2385	190	200	150	12	2937	30				5.15	1120		2.20	2.37		Operating at 80 volts
259	CS				2150	6	21	2177				32	6.05	1440	0.38			0.36	Operating at 80 volts Ore after control
260		Alloy Steel													No Carbon		Pick Up	Apparent.	Operating at 110 volts
261	CS				2602	8	24	2634					4.40	1120	0.25			0.65	Operating at 110 volts
262	C1		1926	510		177	19	2692	30	3			4.30	880		2.11	2.75		Part of Silicon did not melt 80 volts
263	CS				2003	10	24	2037				30	6.00	1440	0.32			0.86	Future operation at 110 volts
264	C1		1738	420	149	150		2457	25				5.40	1120		1.77	1.96		Coke added at first; Silicon added to clean bath
265		Alloy Steel														No	Report		
266	CS				2521	28	27	2656					5.30	1360	0.23			0.52	
267	C1		1899	455	175	90		2619	22*	5			3.00	480		1.74	1.98		Hot furnace
268	C1		1911	428	161	128	18	2646	22	5			5.00	1120		2.90	1.50		Graphite used; Silicon added to clean bath
269	CS			95	2760	8	14	2877					5.05	1600	0.21			0.67	95 pounds Manganese steel not iron
270	C1		1956	410	151		18	2535	18	25			3.50	880	(0.00)	2.88	.98		Graphite used; Ground Electrodes Sand
									18*						(0.10)	2.22	1.01		Added Silica Sand and Coke added to get
															(0.20)	1.80	1.05		reduction
271	CS				2532	7	27	2566					5.00	1440	No	Report			
272	C1		2451	218	165		18	2852	18							2.91	.80		Graphite added at first heat
									18*	30			6.00	1120		2.80	.84		After twenty minutes reduction of Silica
273		Alloy Steel													Slight	Carbon	Pick Up	Apparent	
274	CS			50	2464	8	17	2549					4.25	1200	0.27			0.68	50 pounds Manganese Steel not Iron as report
275	CS				2302	6	21	2329					5.40	1200	0.23			0.69	
276	C1		2351		173	150	15		25				3.15	1280		2.82	1.39		Silicon added to clean Bath with Coke addition
277	CS				2508	3	23	2538					5.10	1200	0.20			0.55	
278	C1	335	1380	700	120	40		2575	50				3.15	640		2.96	1.38		Silicon added to clean Bath
279	CS				2576	7	24	2607					5.50	1360	0.35			0.54	
280	CS				2070	26	20	2096					4.55	1120	0.16			0.45	

[1]See Table 1 for Scrap Iron Classification.

Table No. 3 (Continued)

Heat No.	Material	Charge in Pounds							Coke Pounds	Silica Sand Pounds	Graphite Pounds	Iron Ore Pounds	Time Hours	KWH	Analysis			NOTES
		Scrap No. 6	Iron* No. 3	No. 4	Steel	Fe Si	Fe Mn	Total							C	Si Per cent	Mn	
335	CS				2236	6	28	2270					6.30	1520	0.24		0.58	Cold furnace poured at 2850 F.
336	C1		2290		140			2430	150	Silicon	Carbide		5.25	960	3.05	1.13		Silicon Carbide used
337	C1		2292	110		60		2362					3.30	640	2.75	1.93		Second heat of day
338	C1		2002	510		110					50		6.00	960	No	Analysis		
339	CS				2200	10	37	2247					9.15	1600	0.25		0.87	Delayed by Electrodes sticking
340		Alloy	Steel															
341		Furnace lining fell in. Heat Scrapped											9.00	1840				Last heat from lining Walls and bottom 551 heats Roof replaced and kept for spare
342	C1		1227	827		120		2174					4.45	800	3.00	2.01		
343	CS				2014	8	28	2048					3.55	880	0.32		0.72	Difficult to slag clean
344	C1		1312	723		120	8	2163					3.00	480	2.90	2.55		Second heat
345		Alloy	Steel															
346	CS				2000	6	32	2038					3.20	800	0.32		0.73	
347		Alloy	Steel															
348	C1		1260	945		132		2337	15	20	40		3.30	560	1.95	2.87		Second heat
349	CS				2007	6	29	2042					4.55	1120	0.25		0.60	
350	C1		870	1404		132		2343	50				4.30	800	2.21	2.59		
351	CS				2088	6	30	2124					5.00	1040	0.35		0.74	
352	C1		426	1786		132		2344					5.00	800	2.02	3.31		
353	CS				2229	6	33	2268					4.40	1040	0.37		0.73	
354	C1		1159	850				2009	25	65			2.50	560	2.58	1.22		Silica reduction attempted
355	CS				2012		31	2043				35	4.10	960	0.28		0.57	
356	CS				2007	4	28	2039					4.05	1120	0.18		0.53	Furnace down four days
357	C1	600		1415		120		2135					4.10	800	2.05	4.13		Scrap high in Silicon
358	CS				1607	4	23	1634				125	6.35	1200	0.37		0.79	Control when melted 18% Carbon Twenty minutes later 40% Carbon
359	CS				2003	6	28	2037					5.40	1200	No	Analysis		Bottom has been fixed to make it easier to scrape after heat
362	C1	263		1747		120		2130	40	20	20		4.30	640	3.16	2.91		Graphite used
363	CS				2015	6	28	2049					4.45	960	0.27		0.73	
364	CS				2034	5	30	2069					5.10	960	0.28		0.80	
369	C1	End of Cupola Heat. Charge all No. 2 Iron													3.21	1.20		

*See Table No. 1 for Classes of Scrap.

In heat 354 silicon reduction from the slag was again tried with no better results than on the previous attempts.

To get a cheaper source of silicon 3.5 per cent silicon pig iron was purchased. Using this pig iron very little silicon is lost from the initial charge.

Heat 369 is a cupola heat made from the same material used in the electric furnace under No. 3 iron in the table.

Cost Factors

In speaking of the costs of electrically melted cast iron it is impossible to make any general statements in dollars and cents which will apply in all parts of the country but for similar methods of operating there are many amounts which can be given to facilitate making comparisons.

It has been found that electrically melted iron should contain a total carbon and silicon content of 5 per cent. Whether the charge is brought to these figures by ferro alloys, pig iron or other means depends upon the relative value of the materials and does not affect the resulting iron. When ferro silicon is used there is usually a heavy loss. The carbon can be raised by ground coke but unless this coke is clean and low in ash the resulting carburization will be small. Graphite from broken nipples or electrodes ground to pass through a ½-inch riddle will give very good results. The difficulty of grinding this material makes it as expensive as carbon raising graphite supplied by graphite companies.

Power consumed will vary according to the temperature at which the iron is poured, the amount of carburizing done and the efficiency of the furnace and melter. If the iron is run as a second heat of the day it should take one-half the electricity used to melt the steel. If it is the first heat of the day it will take about two-thirds the electricity consumed by a similar steel heat. These figures are conservative as the months average for iron. The actual consumption per ton for the year is 593 KWH for iron and 952 KWH per ton for steel. During one month iron was run only as second heats and the average for that month was 495 KWH per ton for iron and 962 KWH for steel. During the

period that these observations were made the KWH demand was kept below 312.

The electrodes consumed for melting iron has not as yet been determined definitely, however, from observation there does not appear to be any more than for steel.

The wear on the bottom is no more than with steel if as much. The temperature on the roof is much milder. The walls and bottom are never heated as hot, the only noticeable wear at all is the scraping of the bottom after the heat is poured and the material removed averages less than thirty-five pounds, the large portion of which is half molten iron and a slag similar in appearance to dirty carbide.

The tools used to ravel the bottom and skim the bath will be rapidly consumed by the iron. It has been found that a test spoon coated with soot from an oil burner will clean easily after taking an iron test. About five pounds will be eaten from the ravels each time the bath is skimmed if they are allowed to get too hot before they are changed for cold ones.

The time will vary according to the demand which is maintained. It is safe to say that due to the difficulty in getting contact it will take half an hour longer to put the current into a charge of iron than it would to put a similar amount of electricity through a bath of steel.

Another factor is the loss of metal. It would seem that the losses in the electric furnace should be less than with the cupola, however, it has been found that if a heat is poured cold there will be 25 per cent loss in the electric furnace. It is possible that this iron is picked up in the following steel heat and analysis would indicate that this is the case. With a hot heat of iron the loss is practically confined to the metal drawn off while skimming the bath.

Summary

Melting

1. 110 volts is found suitable for melting iron. 80 volts consumes more electrodes with slight carburization.

2. Care in charging heavy pieces first will help in maintaining electric contact.

3. Graphite added to a clean hot bath and stirred with a green pole will give good carburization.

4. Ferro-silicon added to the bath to increase the silicon will give problematic results unless the conditions are maintained exactly the same.

5. It is important to slag all graphite off the bath before pouring.

6. After the bath is poured the bottom must be scraped clean of all loose material.

7. Ore in the following steel heats is not necessary.

Resulting Iron

1. The carbon-silicon content should be 5 per cent in order to obtain soft iron.

2. Iron of similar composition from the electric furnace and cupola will vary in hardness, machinability and size of grain. The electric furnace iron has a closer grain.

Costs

1. Where the electric furnace is not used to capacity in melting steel, iron can be melted to consume the surplus power without increasing the cost of steel made in the same furnace.

2. The silicon necessary to obtain soft iron makes the cost high unless high silicon, pig or scrap is available.

3. Additional wear on the furnace lining due to the iron is negligible.

4. Unless the iron heats are brought to a comparatively high temperature there will be a heavy loss of iron and trouble in the following steel heats with high carbon.

5. Pig iron is not necessary to obtain good iron provided the charge is brought to the desired analysis with ferro alloys or scrap.

DISCUSSION

CHAIRMAN L. L. ANTHES: I want to thank Mr. Lamb for his paper To many of us this is a most interesting subject. As you know, the melting of cast iron in the electric furance is more or less of a new procedure and is still in what we might call the pioneer stage. There are a great many economic factors entering into it, because, as you know, in some places in the farther west and on the Pacific coast, pig iron is not easily available nor is coke. There is a great hydro-electric development going on all over the country and in some localities very advantageous arrangements can be arrived at whereby if a foundryman wishes to get power at off-peak loads, he can make a very favorable arrangement indeed.

We had a number of papers last year showing a great deal of interest has developed in this subject, and alternating the electric furnace for steel and cast iron presents many new problems. Making cast iron in the electric furnace is not a standardized practice, such as melting in the cupola, and as Mr. Lamb has pointed out, it still demands a great deal of experimentation.

J. T. MACKENZIE: The point I would like to find out is how this other foundry Mr. Lamb speaks of gets the carbon up high? We have all dabbled on this and everybody who has used an electric furnace for grey iron tries to get the carbon up. Three and a half seems to be about the points at which we all quit. I would like to have Mr. Lamb explain how other foundries manage to get it up higher.

G. E. LAMB: That is what I would like to know, too, because I do not want to use so much silicon. I was talking with a man from the coast and he says they are using steel scrap as a base for their charge. They do not start in with cast iron at all. He says they put in their carbon and steel at the same time, mixing it thoroughly as they charge; they are using this creosote carbon, or carbon coke, and when they melt down, they come down with 3.25. Then they use a green pole and stir the bath well and they skim it and put on another layer of this creosote carbon, and they get their results of higher carbon, but I have not succeeded in doing so. This man stated they get carbon about 3.30 to 3.40, but he did not have an exact analysis.

J. T. MACKENZIE: Of course my interest is in cast iron pipe and I believe it is practically impossible to make cast iron pipe with carbon below 3.40. It should be at least 3.50 or 3.60. If any of you have ever stood on the business end of a greenpole in front of a hot bath of electric iron, trying to get another 20 points into the bath, you know what we are talking about, when we say that putting it in with a green pole is certainly not a pleasant job. You have to pay a man pretty high wages to make him stay there.

H. RAYNER: I would like to ask Mr. Lamb, if by creosote coke, he means petroleum coke?

G. E. LAMB: I do not know where it comes from. We purchase it from the Creosote Company, that is all I know.

H. RAYNER: That would likely be from coal tar products. Do you notice any difference in the absorption of carbon by the variation of temperature? The higher the temperature, the greater the absorption?

G. E. LAMB: Yes.

R. R. KENNEDY: I am wondering what effect the silicon content would have on the amount of carbon the iron would take up. The higher we run our silicon, the less carbon we take up, and the lower silicon iron would likely take up a greater amount of carbon content than the higher silicon iron.

J. T. MACKENZIE: I was rather closely associated with the Anniston Electric Steel Company when they were making washed iron and they found practically silicon free baths resulting from what was left after the oxidation of phosphorous. It did not take much more work to get the carbon to 3.50, but they never even tried adding silicon first; they always added the silicon after they had accomplished the addition of all the carbon they wanted.

R. R. KENNEDY: Did you use the electric furnace in the making of cast iron?

J. T. MACKENZIE: Yes, sir.

R. R. KENNEDY: I thought you found that too expensive?

MR. MACKENZIE: We did and we knew when we were whipped and quit.

CHAIRMAN ANTHES: I do not want any of those here to be discouraged by what Mr. MacKenzie has said, because he carried on a great number of experiments in the south and went at it in a large way. He does not mean that he was beaten at the game, but that, under the conditions prevailing, that he did not save money.

J. T. MACKENZIE: That is it.

CHAIRMAN ANTHES: That condition may be reversed at these points further west. I do not think that Mr. MacKenzie means that it is a dead issue by any means.

J. T. MACKENZIE: No; when we started out we had a $15.00 differential with the class of materials we could use with the electric furnace and what we could use in the cupola for making pipe. The electric furnace cost us about $6.00 a ton straight, but when the differential went down to $5.00, there was nothing to it, no economy in using the electric furnace.

A MEMBER: Do you mean that was the cost of melting?

J. T. MacKenzie: No, that was the cost of the duplex.

A Member: I would like to ask the speaker about the efficiency in the absorption of carbon and how much loss you have to figure on in the carbon addition. Another question I would like to ask is in connection with the cost of power. In running over the figures, I see that the average power consumption for steel is 952 kilowatt hours per ton of steel. I had some experience in melting steel some years ago, and our average was in the neighborhood of 700. It seems to be altogether too high. I was wondering whether or not the length of time for melting a certain amount of steel did not have a great deal to do with it. I should like to ask also how long it took to melt a ton of iron.

G. E. Lamb: It does have a great deal to do with it. In the first place 900 kilowatt hours per ton is operating at 300 k. w. demand. In Table I, for instance, we have a ton heat taking up four hours. Now I imagine a ton heat that you were melting took you a great deal less than that. Iron and steel both took us about the same time, although the total time for iron was less because of the less kilowatt hours put in. As to the efficiency of the absorption of graphite, I have not figured that out, but it could be figured. On Table 3 we have 50 pounds of coke and 2300 pounds of iron in the heat. Our final analysis was 2.21 carbon; in other words, on that particular heat we practically did not carburize at all, but I do not think you would find any place that the efficiency of our carburizing element was over 50 per cent. I know that is what I roughly estimated. When I put coke in the furnace I do not weigh it; I just shovel it in with a shovel because it is not worth weighing. We do not start from all steel scrap. The Wallace Foundry, at Vancouver, B. C., starts from all steel scrap.

Synthetic Cast Iron and Its Possibilities for the Seattle District

By G. S. Schaller,[1] Seattle, Washington

It has only been comparatively recently that the melting procedure in the foundry has come under technical supervision. This changing over from a more or less haphazard charging practice to one of technical control has, apparently, worked to the disadvantage of the cupola because its shortcomings have been brought to light and quality in the molten metal has been stressed.

It has been found difficult to go beyond rather fixed limits in producing cupola metal of definite physical properties. The awakening to this condition is rapidly beckoning to the electric furnace as a staple grey iron melting medium. During the past few years numerous experiments in the duplexing of metal have been carried on. In this process, the iron is melted in the cupola because of its cheapness and is then poured into the electric furnace for the refining or duplexing operation. This process results in a metal of much higher physical standards than cupola metal as a result of a certain amount of purification which takes care of such objectionable elements as sulphur and included gases and oxides.

The Synthetic Process

In a recent article[2] there is a definition given of the synthetic process which is quoted below.

"Synthetic cast iron is the term by which, since the commencement of its manufacture in the electric furnace, the inventor of the process has always described the iron obtained by the recarburizing melting of steel turnings. This term has since passed into metallurgical currency, and has now become generic. The novelty of its manufacture consists in carburizing iron and steel scrap, more particularly turnings, by melting these metals in the presence of carbon, which is simultaneously introduced with them

[1]Department of Engineering Shops, University of Washington.
[2]The Foundry, Vol. 48, No. 12, June 15, 1920.

in the melting appliance." Charles Albert Keller, Livet, France, is the inventor of the process.

The history of the development of the electric furnace for melting is similar to the development of other important factors in the iron and steel industry. However, the electric furnace from the beginning had such obvious advantages that its development has been more rapid than that of similar mechanical equipment. The principle of melting iron electrically was first applied by William von Siemens in 1878 and 1879.[3] His equipment consisted of a small crucible containing the metal charge into which two carbon electrodes were introduced.

Siemens' invention went further than successfully melting iron in that he perfected a method of automatic arc regulation which has been used as a basic principle in the design of modern arc furnaces. After Siemens' experiments practically nothing was done with the electric melting process until 1892, when De Laval patented his furnace for the refining of iron. Other early investigators in the electric furnace field were such pioneers as Heroult, Stassano and Kjellin.

From 1900 until 1912 extensive experiments were carried out both in this country and abroad with the electric furnace as a means of producing steel. The results of this experimentation together with certain commercial installations reaching to the year 1915 resulted in general agreement on four basic types of electric furnace design:

a. The direct arc.

b. The direct arc with conducting bath.

c. The direct arc with non-conducting bath.

d. The induction type.

Other types dissimilar in design have proven satisfactory for limited capacities, yet the commercial adaptability leaves something to be desired in each case.

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[3]The Manufacture of Electric Steel. By Frank T. Sisco, McGraw-Hill Book Co. New York, 1924.

Two Major Causes for Development

The rapid strides made by the electric furnace in this country can be traced to two major causes. In the first place early experiments and developments were backed by powerful influences.

The second major cause which gave the electric furnace an impetus it would not have received in any other way was the breaking out of the World War and its subsequent insatiable demand on the iron and steel industry for ordnance material in addition to the standard range of iron and steel products. The former demand was very hard to fill because of the stringent specifications for excellent physical quality necessary to meet ordnance requirements. The question of minimum weight coupled with maximum strength was paramount and called for new methods and new proceses for production undreamed of before.

The field of application of the electric furnace to the manufacture of synthetic iron received its greatest impetus during the war. It can be said in all frankness, too, that its greatest developments and successes were registered during that period. Possibly the most extensive development of synthetic iron manufacture took place in France during the war in the manufacture of cast iron shells. As much as 300 tons per day have been credited to the furnaces located at Livet, France, where a large hydro-electric development is located. The production of synthetic iron in France in 1914 produced by Keller is said to have reached the imposing total of 150,000 tons.[3]

In the United States the production of synthetic iron was undertaken in 1917 by the Sweetser-Bainbridge Metal Alloys Corp. of Watervliet, New York. Canadian foundries were very active in using this process and their production reached 2,500 tons per month during 1917. After the war time demand died, the synthetic cast iron process saw very little activity. With increasing knowledge of the process as well as furnace operation a definite revival has set in which will, no doubt, place this process on a definite basis where it will soon be recognized as a factor in the production of foundry iron.

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[3] "The Foundry," Cleveland, Ohio, Vol. 48, No. 12, June 15, 1920.

Problems of the Industry

The process requires scrap steel or iron for a basic charge to which some suitable carburizer must be added and then the whole is melted in the electric furnace using electric current as the source of heat. Where these three primary factors can be had at reasonable cost, it is obvious that the process will develop rapidly.

The problem in the manufacture of synthetic cast iron is that of melting steel scrap or turnings and at the same time introducing carbon into the mixture in order to gain iron of proper grade. The other alloys present in cast iron can be added to the metal in the ladle in the form of ferro-alloys or else to the furnace bath itself.

With the acid electric furnace definite control can be maintained over the carbon, silicon and manganese elements while the basic furnace gives control over all the principal alloying elements found in cast iron, carbon, silicon, sulfur, manganese and phosphorus. The early investigators encountered considerable difficulty in attaining the proper carbon content and this fact seemed to be of great moment until recent investigators have shown the way of correcting this apparent difficulty.

Robert Turnbull, in 1918, gave the following record shown in Table 1 of consecutive heats in making synthetic iron in the electric furnace. These results were obtained in the early stages of the synthetic process. It is of interest here to note that steel scrap was the metal used in these charges.

The factors affecting the rate of carburization were studied by Williams and Sims and their results reported in a paper "Manufacture of Synthetic Foundry Iron in the Electric Furnace," before the American Foundrymen's Association at its 1923 meeting.[4] The results pointed out indicate that proper carburization can be obtained in a commercial way without serious difficulties arising. They give as a basic charge for one ton of synthetic iron the materials and amounts set forth in Table 2.

The question naturally arises relative to the possibility of producing foundry iron from steel scrap in another type furnace.

[4]Trans. American Foundrymen's Association, Vol. 31, 1924, pp. 154-167.

Some results have been obtained in this connection by such investigators as R. Moldenke, who reports in his text "The Principles of Iron Founding,"[5] having melted thick plate steel scrap in the cupola by using unusually large fuel ratios. Tests of a similar nature are reported by W. B. Wallis. During the war, in Coblenz, Germany, attempts were made to make grey iron from

Table 1

Heat No.	Silicon Per Cent	Sulphur Per Cent	Phosphorus Per Cent	Manganese Per Cent	Carbon Per Cent
254	1.02-L	....	0.016	....	3.42
255	1.10	....	0.019	0.70	....
256	1.15	0.023-H	0.017	....	2.77-L
257	1.40	....	0.015	....	....
258	1.18	....	0.019	0.70	3.21
259	1.10	0.020	0.013	....	....
260	1.10	0.016	0.021	....	3.32
261	1.06	....	0.018	0.70	....
262	1.00	0.019	0.016	....	3.17
263	1.07	....	0.013	0.74	....
264	1.20	0.012	0.015	....	3.48-H
265	1.28	....	0.017	0.75-H	....
266	1.12	0.011	0.021	....	3.07
267	1.00	....	0.014	0.74	....
268	1.02	0.010	0.014	....	3.09
269	1.02	0.011	0.039-H	....	3.18
270	1.28	....	0.032	0.69	3.36
271	1.07	....	0.032	....	3.05
272	1.10	0.009-L	0.021	....	3.10
273	1.20	....	0.030	0.68	2.93
274	1.72-H	....	0.022	....	3.21
275	1.12	0.012	0.028	0.66-L	3.40
276	1.02	....	0.027	....	3.22
277	1.25	0.010	0.013-L	....	3.18
278	1.42	....	0.014	0.66	....
Average analysis	1.16	0.014	0.020	0.070	3.19
Silicon desired				1.00 to 1.25, which is rather low.	

an all steel scrap charge, an ordinary cupola being charged with two tons of coke to 7¾ inches above the tuyeres. After the blast was on, more coke and 350 pounds of burnt lime was charged. Then charges were added of 110 pounds of structural steel scrap, 200 pounds of coke and 66 pounds of lime. With the first five tons of scrap, 900 pounds of 10 per cent ferro-silicon was charged. When tapping, 110 pounds of 75 per cent ferro-silicon in lump form was added to the ladle. The iron obtained ran in carbon 2.70 to 2.95 per cent; in silicon from .60 to .70 per cent. The run had to be stopped, however, because the cupola, about 20 inches above the tuyeres, became bright red. The results obtained are far from being satisfactory from the standpoint of grey

[5]The Principles of Iron Founding, by Dr. Richard Moldenke. McGraw-Hill Book Co., New York, 1917.

iron. It is interesting to compare the results mentioned with those obtained by Williams and Terry, given in a paper before the Electro-Chemical Society in 1922. These results are listed as follows:

HEAT NO. 748—BORINGS CHARGED

	Total Carbon	Si Per Cent
Charge Analysis	3.44	2.12
Heat Analysis	3.39	2.13

These results show a good grey iron made from practically the same material used in the German cupola experiments.

Table 2

Material	Quantity
Steel scrap, turnings, etc.	2,000 lbs.
Carburizer	140 lbs.
Ferrosilicon 50 per cent.	80 lbs.
Ferromanganese 80 per cent	10 lbs.
Electrodes (carbon	24 lbs.
or graphite)	10 lbs.
Limerock	150 lbs.
or lime	75 lbs.
Fluorspar	20 lbs.
Power	750 K.W.H.

The writer conducted some tests with a cupola in the engineering shops at the University of Washington in attempting to produce synthetic iron. Extreme difficulty was experienced in raising the cupola temperature high enough to melt the steel scrap by using coke fuel. Retort carbon was tried in an effort to increase the temperature but poor results were obtained The metal tapped from the cupola was very dull and sluggish and entirely unfit for casting purposes. The metal did show a considerable gain in carbon, its analysis being around 2.5 per cent carbon yet the results were of such an unsatisfactory nature that further experiments were foregone.

The obvious conclusions to be drawn from the above discussion are that synthetic iron is a commercial possibility and that it must be produced by the electric furnace method. Moreover, synthetic iron presents a desirable manufacturing problem when its primary raw materials, steel scrap, carburizers and electric power are available at reasonable rates. The availability of these

materials together with their costs will be discussed in detail in the following sections in which the writer shall endeavor to show synthetic iron production possibilities of the Seattle district.

Material Used in the Synthetic Process

Steel Scrap

The basis of the charges used in the electric furnace is steel scrap of various kinds or cast iron scrap depending upon the character of the final product required. For the making of synthetic foundry iron, steel scrap is used for the base charge for a number of reasons. In the first place, in order to produce a competitive foundry iron by the electric melting process, the so-called "raw" materials must be low in price in order to take care of a fairly high melting cost resulting from the use of electrical power as compared with the inexpensive coke of the cupola. Steel scrap is by far the cheapest material available. Yet, the term "steel scrap" covers a wide range of materials.

The best grades of this scrap viewed from a marketing standpoint are known as heavy melting scrap—a type of material commanding a price comparative to scrap cast iron especially in eastern steel centers. From this classification, steel scrap ranges in price down to turnings, borings and light materials. It is the materials in this latter classification that do not command a satisfactory price because of a lack of market for them. Even in eastern mill centers such scrap is quoted several dollars on the ton under the heavy melting type. The reason for this is not so apparent at first thought, especially when this material originates at or near the furnaces.

The only satisfactory explanation lies in the fact that handling costs are high, due, as in the case of turnings to considerable bulk accompanied by light weight. Some experiments have been successfully conducted in briquetting this type of material to make it more desirable as well as economical for furnace use. This process involves the use of machinery and especially designed material handling equipment which are always attended by expense far greater than any benefit which can come from an improved price on the briquetted material. Another point, too, is that the

finer, lighter materials are given over to rapid oxidation when melted in the open hearth furnace. This means a higher melting loss and, consequently, a lower first cost for the material.

As a result of this condition, light scrap and turnings command practically no market in Seattle and are not very much in favor with the dealers in scrap iron and steel. There exists in Seattle then, a material available for the synthetic process which has practically no market at the present time.[6] Steel scrap is desirable for the synthetic process too, because of its iron content. By using steel scrap no additions of a strictly ferrous material are necessary in the furnace. There are additional elements needed for an acceptable grade of foundry iron yet there are all present in steel but in much smaller quantities than in grey iron. The entire process is built around re-carburization of the iron present in the steel scrap to which ferro-alloys are added in the proportions required to meet definite specifications.

The synthetic process will create a market for the "off-brands" of steel scrap in the Seattle district not only because of the cheapness of the scrap but because of the important fact that light scrap and turnings are better adapted to the electric furnace process. Turnings in themselves form almost an ideal material being thin in sections, they present maximum surfaces for a given weight of material. This results in better electric conductivity in the furnace and materially increases its operation through the fact that the charge heats more even and at an increased rate over that obtained with bulky material. This point is not so generally understood and yet it can bear considerable emphasis in this problem. Another decisive factor in favor of the light sectioned materials is due to its large area or surface heating rapidly and, consequently, melting at a faster rate than more bulky scrap. That being the case, less time is required to melt the charge resulting in a lower production cost.

The two chief virtues of thin scrap actually outweigh the point of low first cost. However, of even greater importance is the fact that a market will be found for this class of material in

[6]This information advanced by scrap metal dealers with the promise of withholding their names from any published work.

this district on an noncompetitive basis with markets already established.

There is a vast amount of steel scrap of all types available in this district.[7] A considerable amount of this comes from the three trans-continental railway systems whose terminals are here. The exact figures on tonnages of scrap arising from this source are not available unfortunately. The best index can be had from the sales of the scrap metal dealers, the figures on exports obtained from the United States customs office and the information so generously extended the writer.

In addition to the railroad scrap, the repairing and scrapping of automotive equipment is of considerable note. There is, of course, some cast iron scrap in an old automobile especially the motor and the transmission housings. The balance of the car is largely made of steel particularly of light section. Since the trend in automotive body design is toward all-steel construction, the amount of steel scrap from the body will swell an already increasing total. Disc wheels will also find their way to the scrap yards and prove to be more or less undesirable due to their thin sections.

Seattle as a sea port brings in a substantial quantity of steel scrap from repairs to shipping and scrapping of obsolete boats. One of the best proofs of this situation is to note the qualities of chain of various kinds present in all scrap metal yards.

The logging camps and saw mills are other heavy contributors to the scrap yard. In addition, there is some tin plate scrap available from the can making factories in Seattle There is also a wide diversity of metal manufacturing plants in this district which contribute their share of steel scrap.

These various illustrations are cited to show the presence of an enormous steel scrap production in Seattle and one that will continue in greater volume as the replacement of wood by steel continues its relentless advance in the mechanical arts.

Steel Scrap Markets

With such a large steel scrap production the matter of markets at once becomes of importance. It is rather difficult to recog-

[7]See footnote 6.

nize a definite market in Seattle so far as a "market price" is concerned.[8] This statement is based upon the fact that the large mill centers are at a considerable distance from Seattle and prices quoted on steel scrap are usually the delivered price. This condition naturally has a suppressing effect upon the local market because dealers are confronted with paying a freight rate that amounts to a considerable portion of the delivered selling price.

Export trade in steel scrap is not very heavy at present. Figures from the customs office are shown in Table 3.

Table 3

Destination	Amount in Gross Tons
1923	
Japan	2,852
China	178
Canada	104
Kevanting	100
	3,334
1924	
Japan	3,148
China	1,289
Canada	408
Honkong	34
Kevanting	20
	4,899

It is interesting to note from these figures that the recovery of Japan from the earthquake disaster and China from the revolution is directly reflected in their respective steel scrap purchases. The better grades of scrap are exported, structurals being especially in demand. This export business would not, however, interfere with the market for synthetic scrap steel because the lighter materials and not the heavy are wanted.

A local steel company, one of the largest local steel scrap dealers, informed the writer that there is normally 2,500 gross tons a month available in excess of the former's demand. This would appear to mean that approximately 3,000 gross tons a month are now available in Seattle for the manufacture of synthetic iron. This estimate has been purposely increased over that of the scrap steel dealer because of the availability of such material as turnings, borings, etc., for which no market now exists. To this may be

[8] A careful study of the metal market papers of the East shows a complete lack of market information for Seattle.

added such materials as manganese steel and high silicon irons which do not have a ready market yet are valuable in the synthetic process because of their composition.

Carburizers

Next of importance to a ferrous material as a base charge in the synthetic process, is the matter of a suitable carburizer. An efficient carburizer must be one high in carbon and should be of a dense nature. Considerable work on this subject was done at the Northwest Experiment Station, U. S. Bureau of Mines, Seattle, by Messrs. Williams, Sims and Larson. In their paper, "Manufacture of Synthetic Foundry Iron in the Electric Furnace" at a previous meeting of this association they reported on the subject of carburizers, "The purest and cleanest forms of carbon are the best carburizers. As the ash content of the carbon increases, more of it must be used and the rate of carburization will be slower. Artificial graphite electrode or resistor carbon, petroleum coke, gas-retort carbon, and pitch coke, are the best carburizing materials. Wood charcoal ranks high because of its purity but is not as effective as the ones mentioned above because its apparent specific gravity is so low that it floats on the bath giving poor contact. Coke and anthracite coal of low ash content come next in preference, and the high ash cokes last. Silicon carbide is an excellent carburizer but must be used with one of the forms of carbon above mentioned and only in sufficient quantity to introduce the required silicon in the metal."

Of the materials mentioned in the above quotation retort carbon, charcoal and coke are available as local products. Retort carbon is a by-product of a local gas plant.

Charcoal is being made from sawdust by a firm in Bellingham. This process is new and only limited information is available on the subject. It has occurred to the writer that this type of charcoal can be used successfully in some briquetted form. It might be possible to use a pitch binder with the sawdust charcoal so that a product of suitable density and specific gravity would result. This material would certainly form a low cost carburizer and its constituent parts are available in inexhaustible quantities in the Seattle territory. In addition to the carburizers mentioned,

it should be pointed out that bee-hive coke is produced at Wilkeson and Snoqualmie, both near Seattle. These cokes while available for the process have the high ash content objection. Work is under way at both plants which will result in a lower ash content through washing the coal. It is conceivable that a market created for their product through the synthetic process would stimulate the production of a lower ash coke.

By-product coke is available locally from British Columbia as well as the ovens of Western Europe at a price below domestic eastern coke. This coke is low in ash and would, therefore, form a desirable carburizer.

Electrical Power

As pointed out previously, the synthetic process of producing foundry iron in the electric furnace revolves around the availability as well as the cost of the electric power required. The largest production of this process has been achieved at Livet, France.[9] While the modifying circumstances are not entirely available yet the fact remains that Livet is the location of an hydro-electric development of considerable proportions. This leads to the natural assumption that electrical power is available there in quantity and at a sufficiently low cost to make the synthetic process a commercial possibility.

At the present time electrical power is available in Seattle from two power companies. The facilities for furnishing uninterrupted service by both these companies are adequately taken care of through a combination of hydro-electric developments supplemented by steam driven plants. In fact a similarly favorable condition exists throughout the State of Washington.

The results of recent power developments indicate the necessity for a market to take care of the increased power output. It might be well to say a word here about the market for electrical power as viewed by the central station management.

Originally the central station looked upon the lighting load as its market for the electrical energy generated. Before this market

[9]C. A. Keller, "The Foundry," Cleveland, Vol. 48, No. 12, June 15, 1920.

developed to anywhere near its present size however, the use of electrical power began to make itself felt and the second phase of the central station market developed. The increased use of electric motors as individual drives for machinery and their low cost compared to the small sized steam plant found in so many of the smaller factories resulted in the abandonment of the latter in favor of the former to such an extent that the power load in many cases surpassed the lighting load at the central stations.

The third step in this progressive development of central station markets, is now at hand in the form of electrical energy for industrial processes, particularly furnaces, ovens, welding and other lesser power uses. How far reaching this new development will be the writer is reluctant in predicting.

It can be said in all fairness, though, that whenever electrical energy has been applied to the problems mentioned above, the results have been entirely satisfactory and new processes have been made available as, for example, the manufacture of synthetic foundry iron in the electric furnace. It appears that further developments in this direction are limited only by a complete understanding of the possibilities of new inventions and new processes made available by the introduction of electrical power into the industrial field and secondly the necessity of a low cost of electrical energy for these processes and developments.

The synthetic process of making foundry iron is well beyond the experimental stage and furthermore power costs are low in Seattle. As a result, there exists a fortunate condition of circumstances decidedly in favor of a synthetic industry in Seattle. The matter of costs in this connection will be discussed in the section on costs.

The discussion so far as the electrical power situation is concerned has all been from the standpoint of the user. The introduction of a synthetic foundry iron industry is, apparently, just as desirable to the power companies because use could be made of the "off-peak" load and generators could be run to more nearly normal capacities throughout the twenty-four hours of the day. At the present time the peak hours in Seattle extend from 4:30

P. M. until 9:30 P. M., a total of five hours.[10] The hours of this peak indicate that the lighting load is of greatest moment in Seattle, a fact which is consistent with the lack of individual manufacturing enterprises on anything approaching large scale production. The total off peak hours total nineteen which would give ample time for several furnace runs daily, the crews working on the eight hour shift basis.

To show the importance of off-peak loads it can be said that the local power companies offer a reduction of 25 per cent for power used during that time. Such a reduction in addition to quantity discounts offered from the basic rates will react favorably on power costs. There is nothing, of course, to prevent operation of the synthetic furnace for the entire twenty-four hours in the event of contingencies arising demanding such procedure—yet such operation would obviously result in higher power costs, which would immediately be reflected in the costs of the iron produced.

The fact that peak hours occur only at one period during the day is in favor of electric furnace operation because only one shut down is necessary in the day's run and the consequences attendant upon cooling such as lining deterioration are minimized. It has occurred to the writer that since there is only a five hour peak load period, some methods of banking the furnace such as introducing coke upon the hearth might be employed to prevent serious cooling of the furnace. Another possibility, too, is the continued operation of the furnace through the peak period at a much reduced rate—just enough current being used to keep the furnace heated.

The use of electrical power in the synthetic process of making foundry iron would necessitate the installation of transformers and proper power lines. These installations would, however, be made by the power companies and their costs and maintenance would be covered by the cost of the current supplied. The switchboards necessary would be purchased with the furnaces as would all electrical connections used in the plant. The only remaining expense would be that of electrodes. These would properly come under the heading of furnace supplies and will be so treated here.

[10]The same peak load hours are recognized by the Puget Sound Power & Light Co. and by the City of Seattle Lighting Department.

Miscellaneous Supplies

All of the materials necessary for the production of synthetic foundry iron that have been discussed so far, originate in the Seattle territory. These include all of the major raw materials. There are other materials necessary to the process which may also be obtained locally. Among these are included limerock, and refractories in various forms. Limerock is used in the process as a slag forming agent and assumes considerable importance for certain classes of product. There are inexhaustible supplies of this material found along the Puget Sound Country. Possibly the largest being at Roche Harbor. There are other important sources of limerock in northern Washington both east and west of the Cascades.

In the matter of fire brick for use as refractories in the furnaces a source of supply is at hand in Seattle. The desirability of these refractories may be determined from the following discussion of the subject:[11] "All grades of fire clay brick from the highly silicons, kaolinitic to the high aluminous flint fire clay types are produced in the state. . . . high temperature electric furnace work is available for the manufacture of silicon carbide from local quartz." This latter material will prove valuable in the synthetic process for a dual reason, namely: as a carburizer and as a material for adding silicon to the molten metal in order to bring its silicon content up to proper grade specification.

The latter is usually accomplished by the addition of ferro-silicon, a material not produced locally but available from California, the eastern part of the United States or England. The same is true of ferro-manganese. Fluorspar must also be shipped in since no local deposits exist so far as is known.

The electrodes which form a considerable part of the cost item in electric furnace operation are not produced in the west, but are obtained from the East. Japanese made electrodes are also offered on the local market yet their high price over the domestic products does not make them a serious competitive factor.

[11]Hewit Wilson, "The Clays and Shales of Washington, Their Technology and Uses," pages 16-17, University of Washington Engineering Experiment Station Series, Bulletin No. 18.

Labor

In discussing the synthetic process of foundry iron manufacture thus far, the different materials entering into the problem have been treated from the standpoint of their availability in the Seattle district. It is obvious that the matter of labor involved in carrying on the process is of similar importance and interest. The classification for employment in this industry may properly be divided into three groups, namely, unskilled, skilled and technical. These groups are listed in the order of their importance from the standpoint of numbers employed.

In discussing the labor situation, it is necessary to assume that a market exists in which it is possible to employ men who are willing to work shift hours since the synthetic process to be conducted as effectively as possible will demand twenty-four hours a day operation for at least a part of the crew composed almost entirely of unskilled labor. This should not prove to be a serious handicap, however, because shift hours are common in this locality in two major occupations: lumber mill operators and longshoremen. Fishing, too, comes in for rather irregular hours of extended duration. According to the reports issued by the Seattle Chamber of Commerce there is no shortage of unskilled labor existing in 1925.[12] There is present here, however, a considerable element of labor that can properly be termed as seasonal. These men form the bulk of those employed in logging camps, the harvest fields of eastern and the orchards of central Washington. For the most part these men are unmarried and migrate to Seattle during the off-seasons. It is altogether reasonable to assume that a part of this class would locate here permanently if steady employment were open to them.

Present conditions in Seattle point to a continued condition of abundant labor. There are always those available who join the fishing fleets when other employment is scarce. The rapid gain in population of the various Pacific Coast cities creates a sort of labor "pool." Due to abundant ocean travelling facilities between the ports on the coast it is relatively easy for labor to migrate from

[12]Business Outlook for Seattle, 1925. Compiled by Seattle Chamber of Commerce.

unemployment centers to those cities where employment is offered by simply working aboard ship in exchange for transportation.

Skilled and Technical Labor

The skilled labor required in this enterprise can, in reality, be divided into two groups: molders and melters. In addition there will be a millwright crew necessary, containing such mechanics as electricians, brick masons, machinists, maintenance, men, etc. A majority of these men are also closely allied to the building trades—especially the two former. There appears to be a sufficient supply of these men in Seattle due to its expansive building operations and more are attracted here continually from other sections of the United States.

The number of iron molders available here seems to vary with the foundry activity. There does not appear to be a shortage of these mechanics here that is of a pronounced character. The situation here has not received the attention accorded it in the foundry centers throughout the east. The fact is that fewer young men are entering the molding field each year. Large employers of molders are now experimenting with apprentice training courses and trade schools in foundry centers are offering trade courses in an endeavor to make up for the shortage of molders particularly among the young men. Seattle has not found it necessary to interest itself in such work.

Any shortage that might develop in connection with molders should not prove of serious consequence to the proposed synthetic foundry iron industry because, as already pointed out, this industry to survive, would call for large scale production and in that event the industry would have to be supplied with mechanical molding equipment and semi-skilled operators could soon be developed to take care of the molding machines assisted by training foreman and pattern makers.

The matter of securing dependable furnace operators and melters would prove the most difficult. Competent electric furnace operators are not abundantly available in any section, due largely to the newness of the electric furnace or more particularly to the

lack of a complete understanding of its operation or possibilities. It would be necessary to train men for this work—this training involving upon the technical staff employed.

Undoubtedly the college of mines of the University of Washington would prove of inestimable value in this connection in that their cooperation could be sought in enlisting students to elect the courses in metallurgy with the idea of becoming identified with a pioneer industry. Graduates could be employed on some sort of an apprentice course whereby they would be called upon to pass through the various departments of the industry before qualifying for the technical or administrative positions.

If such a plan were put into operation, a splendid source of properly trained men would be available as furnace operators—men who would require a minimum of training because of their previous knowledge of metallurgy and electric furnaces. After these men had finished their shop training they would be extremely valuable to the organization in both the technical and sales branches. Some men would, no doubt, elect to remain on the furnaces for an extended period thereby relieving any shortage that might arise for furnace operators. This plan, if properly worked out, would ultimately insure the industry against any shortage of furnace operators because when a shortage loomed, the technical and sales staffs could be drawn upon for trained men until conditions ameliorated.

Costs

In discussing the possibilities of locating a synthetic foundry iron industry in Seattle, it is necessary to make some estimates relative to the cost of production of this iron. In attempting to arrive at some definite conclusions, the writer has availed himself of data resulting from actual tests conducted in this process. In making up an estimate covering the cost of production of a ton of synthetic iron, it must be borne in mind that the process is still so young that practice that is now accepted as standard, will no doubt be generally improved upon so that should this enterprise be taken up commercially in the future, all cost figures should be viewed in that light.

The various materials entering into the process have been discussed in the preceding sections. There remains then, the problem of quantities and prices of these materials as the subject for this section. The ferrous metal for the base charge would be steel scrap as mentioned in the section on materials. The market price of this scrap for the past several years is shown in Table 4. In reviewing these figures it should be remembered that the market was under government control during the war years.

Table 4

Year	Market Price Gross Tons
1917	$20.00
1918	20.00
1919	11.50
1920	20.00
1921	8.50
1922	9.50
1923	10.50
1924	9.75
1925	10.25

These prices could be shaded somewhat for the low grade of scrap used in the synthetic process. A price of $10.00 per gross ton is assumed here for the purpose of calculation—this price while high seems to be about right for an average over the period since the war, excepting 1920. There is also the likelihood of the market strengthening over its present figures under the stimulating influence of such an industry locating here consequently it appears that a price of $10.00 per ton for scrap steel is conservative.

The next item of major importance is that of the cost of power. In this regard the projected process will show up well in view of the favorable rates offered by the Seattle power companies. The tariff covering the power costs as issued by a local power company reveals the following rates:

First 100 KWH., per month.....4 cents per KWH.
All excess KWH., per month.....1 cent per KWH.

The above rates are subject to the following discounts based upon maximum demand:

1 to 20 HP.....No discount
21 to 101 HP.....12½ per cent discount
101 to 250 HP.....25 per cent discount
250 to 500 HP.....35 per cent discount
500 HP. and over.....40 per cent discount

In addition to these discounts, there is an off-peak discount of 25 per cent allowed. The peak hours are those from 4:30 until 9:30 P. M. each day.

It is believed that in order for the synthetic process to show advantageous costs it would need to operate on such a scale that maximum discounts could be taken advantage of. In that case, current at off-peak hours could be had at a cost of 6 mills per K.W.H. plus an annual overhead charge of $5.40 per year per connected K.W. This latter charge is not actually a direct charge for power—in reality it is a charge for the distributing system which makes possible the delivery of the power. Using this figure it can readily be seen that so far as power is concerned Seattle is admirably situated for the electric furnace industry.

In the matter of carburizers a wide range of prices is encountered due to the quality of the material. Local coke of acceptably low sulphur content is available at about $10.00 per ton; yet the use of this coke would prove undesirable because of its high ash content adding more labor per ton and requiring more power per ton. The writer believes that the suggestion previously made relative to the use of charcoal briquettes would prove to be an economical solution to the carburizer problem. There is, of course, no data available covering the costs of this carburizer so an arbitrary price is largely a matter of speculation.

The other items such as ferro-manganese and ferro-silicon cost about 7½ cents per pound delivered. Graphite electrodes may be taken as costing 25 cents per pound.

An estimate for the cost of production per net ton of synthetic foundry iron based on the amount of material required as shown in Table 2 would results in the figures shown in Table 5.

To these figures must be added the items of labor and indirect materials plus a certain cost for manufacturing expenses. These items can be estimated as follows:

	Per Net Ton
Linings and ladle expense	$2.50
Direct labor	3.50
Mfg. overhead	2.25
	$8.25

These expenses added to the costs shown in Table 5 result in a production cost per net ton of $34.48 which appears to be a satisfactory cost. Unfortunately the writer does not have any comparative costs available for the purpose of checking the above estimate. R. C. Gosrow[13] makes an estimate on the possibilities of the synthetic process and his cost per net ton in the ladle of grey iron using steel scrap are $40.75 from a furnace of 1 ton capacity and $43.60 for a 3 ton capacity furnace. He uses a cost of $15.00 per net ton for scrap and 1.5c K.W.H. for power—the

Table 5

Material	Quantity	Cost	Extension
Steel scrap (turnings, etc.)	2000 lbs.	$ 10.00 gross ton	$ 8.95
Carburizer (Charcoal briquets)	140 lbs.	20.00 N. T.	1.40
Ferrosilicon 50 per cent	80 lbs.	150.00 N. T.	5.60
Ferromanganese 80 per cent	10 lbs.	150.00 N. T.	.75
Electrodes (graphite)	10 lbs.	.25 (lb.)	2.50
Lime rock	150 lbs.	6.50 N. T.	.48
Fluorspar	20 lbs.	25.00 N. T.	.25
Power	700 K.W.H.	0.90c K.W.H.	6.30
			$26.23

balance of his costs are very similar to those shown in Table 5. Allowing for the differences in the costs of these two major items —the costs as estimated by the writer are quite close to those of Gosrow. In estimating the amount of power consumed the figures in Table 2 were followed. It appears though that these estimates are liberal. E. C. Wilson in the "Electrical World," Vol. 82, No. 9, states power consumption per gross ton melted as being as low as 600 K.W.H.

Larry J. Barton in a letter to the writer states that during March, 1925, he operated a 1½ ton furnace for melting scrap, at McGill, Nevada, which consumed 590 K.W.H. per ton charged demand 1000 K.W. These figures are based upon a total charge of 465 tons of scrap. In these runs 85 per cent of the product was white iron which accounts for the low power consumption there being but a small amount required for carburizing purposes.

It is interesting to compare the costs of synthetic iron with those of the cupola melted metal, its greatest competitor. A careful set of cost figures have been kept on melting costs in the foun-

[13]Journal of Electricity and Western Industry. R. C. Gosrow. Vol. 47, No. 7.

dry of the department of engineering shops at the University of Washington which show that over the period of a year the cost of grey iron in the ladle per net ton is $44.00, exclusive of labor. In other words the figure of $44.00 is directly comparable to $26.23 shown in Table 5.

This difference can be accounted for largely from the costs of the raw materials used. For cupola melting the scrap iron cost $20.00 per net ton and pig iron $36.00 per gross ton as compared with a price of $10.00 per gross ton for steel scrap. A leading local foundry gives its cost of cupola iron in the ladle as being about 2.1c which compares very favorably with the figure already quoted.

A comparison of cupola metal costs with those of the electric furnace shows a decided advantage for the latter from a monetary standpoint alone. Added to this there is the advantage of quality of the metal about which more will be said in a later section.

Market

Pig Iron—Foundry Iron Products

Pig Iron

The advantageous costs as shown in the previous section indicate that the synthetic process of making foundry iron can successfully compete in the foundry iron field in Seattle. The process can go even further, in the opinion of the writer, by entering the pig iron market here. Such a procedure would have been comparatively simple prior to 1924 due to the lack of a source of supply of pig iron. A Utah blast furnace, however, is making itself known all along the Pacific coast because most of the pig iron manufactured is being sold on the coast markets. The service rendered by this furnace makes it possible to deliver orders for pig iron in Seattle two weeks after the order is placed. This pig iron sells at practically eastern market prices plus the carrying charges from the plant to Seattle. The total cost of Columbia pig iron then is but little below that of the synthetic product.

It appears from the foregoing, nevertheless, that the synthetic process can hardly hope to maintain itself purely on a pig iron market. There are two modifications though, that will make synthetic pig iron competitive. In the first place iron of practically any desired analysis can be produced. On that basis alone a considerable market exists. For example, the U. S. Navy Yard at Bremerton buys a special grade of pig iron designated as "No. 4" which is a charcoal iron. They also buy a "special" brand which is high in silicon and low in phosphorus. During the past five years the purchases of these brands of pig iron have amounted to 377 net tons costing $12,136.00.

Since the product resulting from the synthetic process has so many possibilities both from the standpoint of chemical analysis and physical properties, it would appear that a considerable market for special pig iron would be created. This problem would be a technical one whereby the technical staff of the synthetic industry would work in close harmony with the foundry owner with the end in view of developing pig iron of such specifications as to result in a superior foundry product. Such a service would undoubtedly be welcomed by the foundries because of the obvious betterment in their product. An added feature would be the developing of new products by those foundries which may have been hindered by the inability of securing pig iron of desired analysis.

A case in point would lie along the lines of developing a pig iron that would resist corrosion. The steel industry offers several brands of rust resisting and non-corroding steel.

A large potential market exists in the Seattle district for castings that will exhibit non-corroding properties because of their adaptability to marine work. If this phase of the market were properly developed it can readily be recognized that non-corroding cast iron products would displace brass fittings on board ship because of a lower first cost and, furthermore, the necessity of constant polishing would be entirely eliminated resulting actually in lower operating costs to the shippers.

The synthetic process could develop its pig iron market along such lines to a point where they would be non-competitive with

the blast furnace product. From the standpoint of standard brands of pig iron there would be little likelihood of invading the present market due to a slightly higher production cost. The methods employed to gain entrance to the present markets should consist of offering immediate delivery of a quality product. Then, too, a certain amount of pig iron will accumulate at the plant in the form of "over iron." That term means iron melted in excess of the requirements for casting purposes.

Such metal would be poured into pig molds and could be sold at an advantageous price because the largest share of its melting cost would be charged to the castings made. In other words, it is practically impossible to melt just the exact amount of iron required for a certain mold or series of molds so to be on the side of safety a small excess is usually melted—this excess being known to the trade as "over iron." Instead of re-melting it as foundries must do, it could be pigged and sold as pig iron under the circumstances already described. This practice combined with the one described on the development of special irons should result in creating a substantial pig iron market.

It might be well to mention that the present pig iron market for the Seattle district embracing the Puget Sound cities such as Tacoma, Everett and Bellingham, reaches a total of from 7,000 to 8,000 gross tons annually. To this figure may be added the pig iron consumption of Portland, Oregon, which amounts to about 10,000 gross tons annually, making a total existing pig iron market of 17,000 to 18,000 gross tons annually. A possible export business might be developed to bring the total pig iron market to 20,000 gross tons annually.

Foundry Iron Products

In the field of foundry iron products the synthetic process finds itself most comfortably situated. There are numerous reasons for this, the principal one being in the favorable cost of production. To this may be added the fact that castings of superior physical as well as chemical properties are produced and it is in this field that the greatest amount of work would have to be done.

The jobbing business or small lot production field would not prove particularly attractive inasmuch as the sales expenses would be high and it would be next to impossible to keep a satisfactory volume of orders on hand to insure proper scheduling. The plant would have to be kept running to its normal capacity in order to produce at satisfactory costs. Shut downs and intermittent operation of electric furnaces are very expensive. There would be a certain volume of jobbing work available that would be desirable.

At the present time there is a definite trend toward Diesel engine building in Seattle. Such activity calls for castings of high physical standards—especially the cylinders where a dense iron is required. Other parts of the engine could be lightened by substituting stronger castings such as are produced by the synthetic process for the bulkier ones now used. This development would have far reaching effects in the Diesel industry where excessive weight per horse power is now one of the difficulties.

Synthetic foundry iron, because of its superior density, high physical properties and machinable qualities, would be especially desirable for such products as:

Internal combusion engine cylinders

Locomotive cylinders

Brake shoes

Hydraulic pumps and castings

High pressure valves and fittings

Machinery exposed to heavy stresses

Chemical equipment subject to corrosion.

These products all require a dense, strong casting. That the synthetic process results in such castings can be gathered from the information given by R. C. Gosrow,[14] who states, "The electric furnace iron possesses marked properties over the cupola metal, which may be listed as follows:

[14]Journal of Electricity and Western Industry. Vol. 47, No. 7, page 265.

Increased density of iron castings—specific gravity 2 to 5 per cent greater,

Increased compressive strength,

Increased hardness (slight) and toughness, due to increased density.

Electric furnace iron always shows a closer grain for the same silicon content than the cupola metal."

These views have substantially been concurred in by such investigators as Williams and Sims of the Northwest Experiment Station of the Bureau of Mines, Seattle, and others.

A very large consumption of cast iron pipe by the City of Seattle indicates a market in another direction. It is entirely within the realm of possibility that the use of synthetic iron would entirely alter present cast iron pipe specifications. This statement is made because synthetic iron is of superior strength and it would seem the natural thing to cut down on wall thickness thereby lightening the pipe without sacrificing strength. In that event, the enormous cast iron pipe industry would virtually be turned over to the synthetic field of production because lighter pipe would be much easier handled and cheaper to transport. The paramount possibility would be the adding of the non-corroding feature to an already long-life product. Pipe of such specifications whose life would be indeterminate, would prove a highly satisfactory article because the original cost would be the last cost so far as the life of the generation would be concerned.

A favorable cost of production could be obtained by employing the new permanent mold centrifugal type of pipe manufacture, eliminating molding entirely. The Pacific Northwest would offer an increasing market for cast iron pipe in replacing the present wooden stave pipe and in taking care of the requirements of the rapidly growing cities in this section. There always exists the possibilities of the export markets in addition.

A further possibility for markets in the synthetic industry lies in the direction of developing new products. It can be said in all sincerity that the possibilities of the foundry iron castings

are far from exhausted. The developments, if there were any, have all been along orthodox lines and but little pioneerng work has been done. It is for this reason that the steel casting industry has gained so much importance. By proper sales campaigns it would be comparatively easy to show that strong synthetic castings can be used in place of steel castings because of similar strength coupled with lower costs and superior machining qualities.

The field of white iron castings which embraces grinding mill balls, crusher jaws, linings, and rolls would also be an excellent one for synthetic iron. In such work the cost per ton of metal would be even lower than given in the section on costs because the process would not have to be carried out so far as in making grey iron.

DISCUSSION

G. S. SCHALLER: In conclusion, I wish to add this in reference to the added value in producing synthetic cast iron. We are taking a material of scrap value and turning it into a product of marketable value. There is an immense differential value in taking scrap steel at $10.00 a ton and turning out a product worth $50.00 a ton; that is a point that we in America must look to, possibly not in this generation, but in the generations to come. The reason for commerce in this country at the present time is the fact that we are selling more or less of our natural resources. You can see an illustration of that where the lumber is being cut down at a rapid rate. After that process is completed we will be faced with a problem that we should have handled fifty years ago.

In this process we offer a solution towards placing America on a more stable and sound economic basis, giving it a sounder policy than exists at the present time. We need only look to Germany to see what has been accomplished in taking the air and selling it to this country in one form or another. The by-product coke is another case in point. The matter of added value might be used by foundrymen who are going to locate in any city. The foundry process, be it synthetic or cupola iron, is one in which you are actually creating value. Viewing it from that point has led me to write this paper, because we need in the northwest industries of that kind. I am sorry that this paper is so abbreviated. The original paper was 150 typewritten pages, but I knew that a lot of it would not be of interest to you. It might be interesting to say that the City of Seattle alone in the past four years has used over a million dollars worth of cast

iron pipe. Formerly that country used only wood stave pipe, which is now rotting out and being replaced by cast iron, and the suburban development in Seattle and other cities are all going over to cast iron pipe.

CHAIRMAN L. L. ANTHES: Gentlemen, it is particularly pleasing to have men like Mr. Schaller come all the way from the Pacific Coast, from one of our universities out there, to our convention, because it is a great thing to have our universities take an interest in the work we are doing. They have evidently an appreciation of the research work carried on by the American Foundrymen's Association, and the fact that this research leads to better commercial conditions and to savings in the future. I think Mr. Schaller touched upon some very interesting points, in fact, a point I was bringing out when I was speaking a little before and that is the economic values that are possible through the making of synthetic cast iron.

DR. RICHARD MOLDENKE: The paper is so well written that there are no questions to be asked.

CHAIRMAN ANTHES: I do not think Mr. Schaller could ask for any greater compliment than that, coming from an authority like Dr. Moldenke, whose reputation is universal, not only in America but all over the world where foundries are known.

Superheating Iron in the Cupola

By S. J. Felton,* Cincinnati, O.

Three potential thermal effects must be considered when investigating the superheating of iron in the cupola, namely:

1. Oxidation of the metal.

2. Difference between the melting and freezing-range of cast iron.

3. Heat absorption by conduction, radiation, and convection.

The object of this paper is to discuss the relative parts played by these heat sources in the cupola.

Oxidation

Some idea of the potential superheating effect resulting from the oxidation of 0.25 percent silicon may be obtained from the following calculation in which the heat of slag formation is neglected. The oxidation of Si. to SiO_2 gives 7000 calories per kilogram and taking the specific heat of molten iron as 0.25 the theoretical *rise* in temperature of the iron would be:

$$\frac{.9975 \times 7000 \times 0.0025}{0.25} = 69.83 \text{ deg. cent. or } 125.64 \text{ deg. Fahr.}$$

Leopold Schmid,[1] by similar calculations, shows that the oxidation of 0.50 percent Fe., 0.20 percent Mn., 0.20 per cent C., and 0.30 percent Si. may have a superheating effect of 335 degrees Fahr. In view of the fact that some of this heat will undoubtedly be utilized to assist in melting, particularly if the oxidation is extreme, we may safely assume that the maximum amount of *superheat* to be expected from this source is limited to the above figure, 335 degrees Fahr.

Melting-range of Cast Iron

A large mass of information is available on the mechanism of solidification and cooling of cast iron, but there is still room for

*Ohio Mechanics Institute.
[1]Die Giesserei, May, 1924.

research on the heating and melting of this alloy. Under conditions of complete equilibrium a specific cast iron will melt at a certain temperature or range regardless of whether it is grey or white. There may be some difference in the manner of melting, however. A large percentage of ordinary white iron will melt as a eutectic of austenite and cementite, but as there is no free cementite in a hypo-eutectoid iron, such eutectic is not present to melt; so the equivalent melting must take place entirely as a solid solution at a constant temperature with gradual absorption of graphite, unless an austenite-graphite eutectic exists. The observations of different investigators on the plastic condition of grey iron in the melting process, should cast doubt as to the existence of an austenite-graphite eutectic, at least under the conditions of commercial heating.

It has been shown that, in practice, irons of the same ultimate composition but with different proximate or structural characteristics, may melt at different temperatures or ranges because of the unstable conditions produced by commercial melting furnaces. The experiment and calculation of Highriter and Schwartz[2] indicate that the grey iron which was heated under conditions comparable to air furnace practice, started to melt at 2160 degrees Fahr. and was completely fused at 2362 degrees Fahr. Under the higher melting speeds which may exist in the cupola, the reabsorption of graphite may be more greatly retarded, thus causing a higher melting range. There is a possibility that the large segregated graphite flakes in pig iron, may resist reabsorption more than the finer more equally distributed graphite particles in thin castings and scrape.

Taking the mean ranges of different investigators, it apppears as though different cast irons may vary in melting, from 2000 to about 2300 degrees Fahr. As these irons, on cooling, are not completely solidified until the eutectic point, in the neighborhood of 2000 degrees Fahr. is reached; it can be seen that this difference in the melting and freezing-point may account for a superheating above freezing, of about 300 degrees Fahr., in certain instances.

2. H. A. Schwartz, American Malleable Cast Iron, 1922, Penton Pub. Co., Cleveland.

Conduction, Radiation, and Convection

The superheating effect on molten iron in the cupola, of conduction, radiation, and convection from incandescent coke, gases, and radiant lining has undoubtedly been underestimated by cupola writers in the past. Nothing could be more conducive to heat absorption than the splitting of iron up into small drops, as is done in the cupola, and then placing those droplets in such close physical contact with the heating media. This is particularly true of iron which melts 46 inches above the tuyeres, or higher, and then the drops fall intermittently from one piece of incandescent coke to another, several feet to the earth. It can be shown that if a tapping temperature of 2670 degrees Fahr. is obtained from an average cupola, the chilling effect of the blast and external radiation from the hearth and bottom dissipate sufficient heat so that the metal must have been heated to at least 2800 degrees Fahr. in the cupola. A table showing the melting and superheating of different types of irons may now be constructed, using the observations in this paper as a guide, the oxidation losses of which, will be based on the writer's practical observations.

	A	B	C
Mean melting range of the iron, degrees Fahr.	2300	2200	2000
Temperature increase by oxidation, deg. Fahr.	335	250	200
Temperature increase by conduction, etc., degrees Fahr.	165	350	600

Column A represents a refractory cast iron melted in the CO_2 zone. The maximum superheat by oxidation is effected, but because of the short distance traveled by the molten metal, the absorption by conduction, etc., is small. Column B can be thought of as representing the same iron melted in the $CO+CO_2$ zone: the slower melting speed causing a lowering of the melting-range, and the higher position of melting in the stack, lessening oxidation and facilitating absorption of heat by conduction, etc. In explaining column C, the writer has melted eutectic cast iron, obtaining tapping temperatures which indicated that the metal was heated to 2800 degrees Fahr. in the cupola, and the oxidation losses were so small that they could only account for 200 degrees

of superheat. The remaining 600 degrees must, therefore, have been obtained by conduction, radiation, and convection.

In view of the predominate effect of conduction, radiation, and convection, in these days of chill pig, the condition of the high temperature zones in the cupola is all important. The physical quality of the coke has an enormous effect on these zones. The writer has seen a change of 200 degrees Fahr. in tapping temperatures result from changing to coke of different quality during a heat. This change took place long before the new coke had an opportunity to get down to the combustion zones, indicating that it was not calorific value, but physical structure which caused the change in temperature. From the description of the new Schurmann[3] cupola, it would seem as though this improvement, or modifications along this line might offer as its greatest advantage, the ability to handle varying grades of coke; because in this furnace the intermediate coke charges should have practically no effect on the blast pressure.

Cupola Theories

The writer[4] has previously presented some theories on the cupola, the salient features of which four may be summed up in four points:

I. The use of moderate excess coke acts as a desirable safety factor, and does not lower tapping tempertaures.

II. Low melting-temperature iron must melt high in the cupola to insure sufficient superheat.

III. The rational method of investigating a cupola heat is to record temperature, volume, pressure, oxidation losses, etc., throughout the heat.

IV. There is a compensating mechanism which enables satisfactory metal to be produced under a variety of cupola conditions.

Points I and II are illustrated in column C shown earlier in this discussion. This metal with a mean melting-range of 2000 degrees Fahr. must melt high in the stack so that the long drop of the molten metal through the hot zones will pick up the large

3. Preheat Blast in New Cupola. The Foundry, Dec. 15, 1923, pp. 994-6.
4. Foundry, May 1, 1923, pp. 351-2; Foundry, April 1, 1924, pp. 255-7.

amount of heat necessary to make up for its deficiency in melting-temperature. A moderate excess of coke is necessary to accomplish this.

Some of these points are indirectly substantiated by A. Wagner[5] in his interesting cupola investigation, in which he records pressure, tapping temperature, flue gas temperature and analysis, throughout several heats. One of his best charts, in regard to uniformity and degree of tapping temperatures, shows a high percentage of CO in the flue gases, indicating that a moderate excess of coke, or its equivalent, a moderately light blast, was being used. It is interesting to note that his tapping temperatures remained reasonably constant in the most of the heats, while the pressure, flue gas temperature, and fine gas analysis varied to wide extremes. This represents additional proof point IV.

F. Schulte and R. Spolders[5] give some interesting cupola charts showing the analysis of the metal and oxidation losses throughout the cupola heat, which is in line with point III.

The Cupola Heat-Balance

In most furnaces the heat-balance is of utmost importance, but this is not true in the case of the cupola. Possibly this is the reason why so few attempts have been made to strike such a balance on this furnace. Richards gave a brief, incomplete balance in his Metallurgical Calculations. Leopold Schmid give some very complete heat-balances on cupolas and reaches some interesting conclusions. In the ultimate analysis of foundry costs, however, the *thermal* efficiency of the cupola is a small item compared with its efficiency as a producer of high quality, high temperature metal. The writer contends that such results are more readily obtained with inefficient thermal operation, than when operating at the maximum thermal efficiency. The main significance of the cupola heat-balance is the determination of the amount of heat lost from the hearth and bottom, as this is at the direct expense of the temperature of the molten iron.

5. Die Giesserei, May, 1924.

Methods of Increasing Superheat

Low tuyeres and continuous operation combined with intelligent pouring methods,[6] would considerably increase pouring temperatures in many foundries.

The preheating of the blast should cause higher temperatures in the cupola, and thus result in hotter metal.

White paint, or any other means of retarding radiation from the hearth and bottom should be beneficial, because heat lost from this area is supplied by the molten metal exclusively. Apropos of this thought, that type of wind box which allows the cold blast to circulate the hearth thus enormously increasing the rate of heat transfer from the molten metal by convection, is detrimental to high tapping temperatures, and could more profitably be replaced by some type of bustle pipe.

In the last analysis, the most positive method of increasing and insuring superheat seems to be the duplexing, or Elliottizing of cupola iron in the electric furnace.

6. S. J. Felton, Study Pouring Temperatures; The Foundry, Feb. 15, 1923, pp. 138-140.

DISCUSSION

R. S. MacPherran: First, what are the author's recommended size of tuyeres? Tuyeres of course are liable to get bunged up and it always seemed to me that a little safety factor should be given in the matter of size. We would like to know his opinion as far as the shape and size are concerned. Our experience is that the most effective shape and size is to put a belt around the furnace for the lower tuyeres. It would be also very interesting to know the speaker's ideas as to the pre-heating of the blast.

S. J. Felton: Any of you who are familiar with what I have previously published on the cupola will realize that I have tackled only a very small phase of cupola operation in getting high temperature metal. I have never said much about design. I do mention design in this paper very briefly. I agree with everything, practically, that Dr. Moldenke puts forth in his Principles of Iron Founding, on the construction of tuyeres and how to make up a charge and how to put it into the stack, etc. My

main points have been what takes place in the stack after the iron gets in there. Personally I have found iron of fairly high temperature coming out of stacks with high charging platforms and low charging platforms and some of them with tuyeres poked in there with a crowbar.

I think that circular continuous tuyeres look quite ideal to me. There is one thing I want to mention in regard to this paper, referring to the table on the third page, items A and B. My conception is that there's two ways a cupola can be run. A is the process advocated by most technical writers and the process which we are all trying to approach, namely, that to control variables as much as possible, melt at a high speed right in the CO_2 zone and have comparatively high oxidation and low pick-ups by conduction. This can be done where we can control variables. In most small foundries where variables cannot be controlled they melt by the second method of using a little excess coke and melt higher up in the stack. As to pre-heating the blast, of course that can be done as you have seen by the paper by Dr. Schurman as presented in The Foundry of Dec. 15, 1923.

W. J. KIHN: I personally feel that foundrymen in the past have stressed a litle bit too seriously the wide coke ratio. I remember in the early days and in the earlier literature and in the convention programs, that a foundryman's melting ability was largely judged by the number of pounds of iron he could melt per pound of coke. In later years, however, that is rarely discussed or mentioned. We all find it in our cupola reports and expect to look at it and scan it. We use it in our reports largely as an index of the condition and value of the coke that we are using. In this day and age, we seem to be rather well agreed, particularly when we must melt quality metal, that an excess over the old ten to one ratio is leaning on the safe side.

Cupola Melting Rate as Affected by Tuyere Ratios

By J. Grennan,* Ann Arbor, Mich.

The cupola seems to be quite a simple melting device, but the difference in construction and operation of the cupolas in different foundries is far greater than the difference in the type of castings produced would justify. Not only is there a wide difference in the cupolas in foundries producing different types of castings, but there is just as great a difference in the construction and operation of the cupolas in foundries producing the same type of castings. This is particularly true of the tuyeres.

The tuyeres in different cupolas vary so much there seems to be no rule or reason for the difference. Some foundrymen use one kind of a tuyere and some another. It is not unusual for a foundryman to buy a cupola and discard the tuyeres furnished by the maker and to install tuyeres more to his liking.

The size and shape of the tuyeres vary as well as the number and location. The size of the tuyeres is usually stated in terms of the ratio of the cross-sectional area of the cupola to the total area of the tuyeres. This tuyere ratio varies greatly in practice in different cupolas.

A series of experiments were run in the foundry at the University of Michigan to see if there was any marked change in results obtained by changing the size of the tuyeres.

Equipment Used

The cupola at the university is a No. 3 Whiting, lined to 32 inches. The blower is a No. 3 Roots, driven by a variable speed motor. With this equipment it was possible to vary the size of the tuyeres and still get the same volume of air into the cupola.

The tuyeres, as furnished by the Whiting Company, consisted of four tuyeres of the continuous type. The tuyeres were each 3¼ inches by 16⅝ inches at the inside of the lining. They

*Foundry Instructor, University of Michigan.

were equally spaced. The tuyeres had two vanes in each to distribute the blast. These vanes cut each tuyere into three sections.

Reducing the Tuyere Area

The vanes in the tuyeres made it easy to reduce the tuyere area by stopping up the sections with clay. The first reduction was accomplished by stopping off the center opening and leaving the sides open, making eight small tuyeres 3½ inches by 5 inches. The second reduction consisted in stoppping off two-thirds of each tuyere leaving four tuyeres 3¼ inches by 5 inches. The third reduction was to reduce the 3¼ inch by 5 inch tuyeres to 3¼ inch by 2½ inch. The fourth reduction was to reduce the four 3¼ inch by 5 inch tuyeres to four 2½ inch round tuyeres. Stated in terms of the ratio of tuyere area to cross sectional area, the reductions were as follows:

Original tuyere area 1 to 3.7 cross section of cupola area.

First reduction tuyere area 1 to 6.2 cross section of cupola area.

Second reduction tuyere area 1 to 12.4 cross section of cupola area.

Third reduction tuyere area 1 to 25 cross section of cupola area.

Fourth reduction tuyere area 1 to 41 cross section of cupola area.

Operation

One heat was run with each reduction except the 1 to 41 ratio when two heats were run.

The charging of the cupola was the same in all heats. A bed charge of coke 36 inches above the tuyeres was used with a 600 pound charge of iron, 50 per cent pig and 50 per cent scrap. The succeeding charges were composed of 75 pounds of coke and 600 pounds of iron.

The blower was run a little faster with the 1 to 41 ratio to allow for greater loss in slipage and leaks in the piping due to

Table 1

HEAT No. 17—TUYERE RATIO, 1 TO 41

Time P. M.	—Pressure in Ounces— In Windbelt	In Cupola	R. P. M. Blower	Tap Number	Time P. M.	Temperature Degrees Fahr.
3:15	9.	6.	278	1	3:25	2604
3:25	10.	7.	278	2	3:30	2650
3:37	10.5	7.2	280	3	3:36	2634
3:45	10.4	7.1	283	4	3:43	2634
3:55	10.2	7.	283	5	3.47	2602
4:05	10.4	7.	280	6	3.51	2634
4:15	10.2	7.1	283	7	3:55	2594
4:25	8.5	5.	284	8	3:59	2594
Average	9.9	6.7	281	9	4:03	2626
				10	4:05	2634
				11	4:10	2602
				12	4:15	2578
				13	4:19	2586
				14	4:25	2586
				15	4:29	2282
					Average=	2600

Table 2

HEAT No. 18—TUYERE RATIO, 1 TO 3.7

Time A. M.	—Pressure in Ounces— In Windbelt	Cupola	R. P. M. Blower	Tap Number	Temperature Degrees Fahr.
10:28	6.	5.5 oz.	265		
10:33	7.	7.	275		
10:42	8.	7.	272	1	2586
10:47	7.5	7.	270	2	
10:52	8.	7.	270	3	
10:57	8.	7.	270	4	2602
11:02	8.5	7.5	266	5	2586
11:08	9.	8.	273	6	2586
11:13	8.5	8.		7	2586
11:23	8.	7.	280	8	2602
11:28	8.	7.	275	9	2586
11:33	6.	5.	272	10	2570
Average	7.7	6.9	271.6		2588

Table 3

HEAT No. 19—TUYERE RATIO, 1 TO 3.7

Time P. M.	—Pressure in Ounces— In Windbelt	In Cupola	R. P. M. Blower	Tap Number	Temperature Degrees Fahr.
3:	6.5	6.5	280		
3:05	7.	7.	270		
3:13	8.	8.	270	1	2650
3:18	8.	8.	270	2	2678
3:25	8.5	8.	270	3	2685
3:32	8.5	8.	270	4	2678
3:39	7.5	6.5	270	5	2642
3:46	6.5	5.5	285	7	2594
3:51	4.5	3.5	290	8	2570
Average	7.2	6.7	274		2642

higher pressure. The pressure developed by reducing the tuyeres was tested with the cupola empty and was found to be very slight with the original tuyeres, about half an ounce for the 1 to 6.2 ratio, 1 ounce for the 1 to 12.4 ratio, 2 ounces for 1 to 25 ratio and 3 ounces for 1 to 41 ratio. The temperature of the metal at the spout was taken with an optical pyrometer.

Tables 1, 2 and 3 give the pressures in the wind belt and inside the cupola at the level of the tuyeres and the temperatures of the

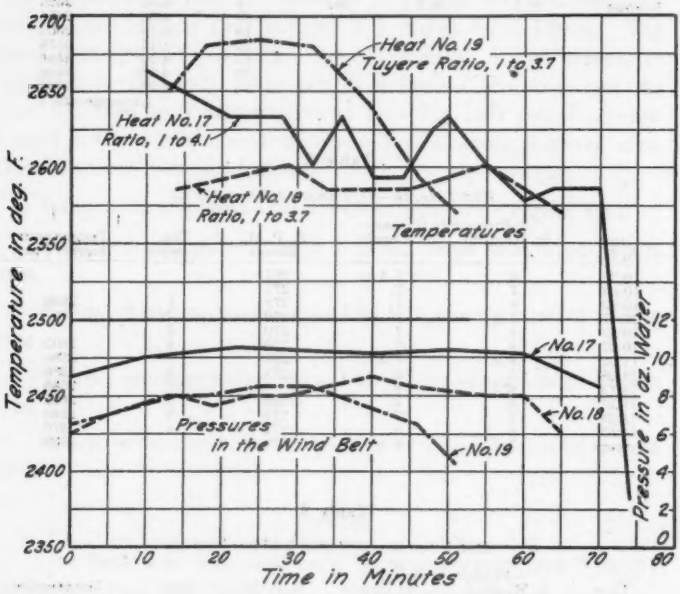

FIG. 1—CHART SHOWING THE RESULTS SECURED WHEN TUYERE RATIOS ARE VARIED.

metal. Fig. 1 gives the principal data of the three tables in graph form.

The average temperature of the metal from the heat with the tuyere ratio 1 to 41 was 2600 degrees Fahr. This is between the average temperature of the two heats with the tuyres 1 to 3.7.

The average temperatures of which were 2588 dgrees Fahr. and 2642 degrees Fahr. The pressure inside the cupola showed very little variation. There was .2 of an ounce of difference inside the cupola between heats 17 and 18. The building up of the pressure was greater with the large tuyeres than the small ones probably because the small tuyeres were kept cleaner due to the small area.

Conclusions

The results obtained by these experiments indicate that there is nothing vital in the sizes of the tuyeres. Foundrymen may discard the idea that small tuyeres will have any marked influence on melting. If their cupola is not working regularly they need not blame small tuyeres for their trouble. It might be advisable to use large tuyeres but within the limits of the sizes in use no foundryman is justified in changing his cupola tuyeres except at such convenient times as when relining the cupola.

The difference in pressure due to the smaller tuyeres would increase the power required to drive the blower.

An Ideal Tuyere

An ideal set of tuyeres is one in which there is the minimum amount of friction offered to the passages of air into the cupola and one which distributes the air uniformly around the cupola. The continuous tuyere of a 1 to 4 ratio satisfies these requirements.

WRITTEN DISCUSSION

V. A. Crosby, Metallurgist, Studebaker Corp., South Bend, Ind.

I wish to substantiate in part Mr. Grennan's contention relative to tuyere ratios. About a year and a half ago we installed four No. 9½ Whiting cupolas. It was decided by the management that these cupolas should be installed exactly as the vendor desired. The installation called for upper row of tuyeres (16-4 inch pipes). We had installed at the same time recording pressure and volume instruments for each cupola. Spencer-Turbo

blowers of the 1½ pound size were installed, this size being recommended because of the height (24 feet) from sand bottom to the charging door. The above is just a preliminary outline of the installation.

We knew accurately the pressure and volume of air being delivered with both rows of tuyeres. We then stopped off the upper row of tuyeres, reducing the intake area into the cupolas 30 per cent. No difference was noted in pressure in wind box, volume of air per minute, or melting rate of the cupola. The resistance to the flow of air in the stack being (24 feet from sand bottom to charging door) proved to the controlling factor. We now operate with a single row of tuyeres of the continuous type at 24 ounces blast pressure and 8000 cubic feet per minute input.

I believe Mr. Grennan is absolutely right and that the foundrymen, before attempting to criticize his paper, should first have definite information relative to their own operations—in other words, watch all the factors involved as Mr. Grennan has done. There has been propagated entirely too much half-baked data on tuyere designs. One should visit a few foundries and see the obsolete antiquated cupola designs around the country where a boiler shell with tubes cut out and four or five holes cut for stove pipe insertion meets all the requirements for the production of excellent quality iron.

I am very glad that Mr. Grennan has seen fit to publish the findings of his research at the University of Michigan and trust that he will continue to chase the mystery that enshrouds the foundry melting department.

DISCUSSION

J. D. STODDARD: I would like to ask if any tests were made, to note the effect on the quality of the mixture. In using the large and small tuyeres the theory has been advanced, and I think pretty well substantiated, that in the smaller tuyeres the force of the blast going through the smaller tuyeres creates excess oxidation. My experience indicates the value of having the proper volume of air delivered with as soft a pressure as possible, and while your pressure as taken in the center of the cupola may be all right, in my judgment there is a point near the outside edge of the cupola where if the air is forced through

under excessive pressure in the smaller tuyeres, the action on the molten iron coming down in globules is more severe and oxidation occurs.

J. GRENNAN: In the case of the one to 25 ratio, the test, as far as physical and chemical properties are concerned, was run very closely and detrimental results were not shown in the chemical analysis or Brinnel, transverse or tension test results. Now the question, of course, would come up as to how far the air would enter the cupola before the force would be broken up. If you look at the graph you will see there an increase in the pressure about the first ten minutes when the cupola is run. You start with fresh coke; that fresh coke burns down and a large piece becomes a small piece, so that it is my belief that the penetration is very slight.

When we ran a 1 to 41 ratio I watched and thought at one time that I saw a permanent effect clear to the center of the cupola. I looked five minutes later and it had disappeared. On the first heat with the 1 to 41 ratio I was rather skeptical; I watched the tuyeres and I opened one with a bar. We can vary the pressure in the center of the cupola by opening from the tuyeres to the center of the cupola. There is a difference between the pressure right at the tuyeres and at the center of the cupola, because there is ash in between there closing up the space between the coke, but I believe the penetration would be very slight.

The air, when it enters the cupola comes in contact with the coke and the coke is right at the tuyeres. All of you have looked through tuyeres and know there is not any large amount of space there for the air to penetrate and the pressure inside the cupola is simply the pressure required to force the draft through the stack. The point is well taken but my opinion is that it is much less than what you assume it to be.

PAUL R. RAMP: I agree with Mr. Stoddard. In the last conclusion here the author says the results obtained by these experiments indicate that there is nothing vital in the size of the tuyeres. Now he is mistaken; there is nothing more vital than the size of the tuyeres. It has more to do with the speed and temperature in melting than anything else but the fuel; the size, shape and location have a great deal to do with it. The minute you reduce the tuyere size you form a nozzle effect and blow down your bed. I say that a tuyere ought to run about 1 to 4 or 1 to 5; that is a lower ratio than the builder mentioned. The builder will run 1 to 6 or 1 to 7. When you run a large tuyere ratio you get a soft blast. The author recommends a 1 to 4 ratio; that is all right; I just take exception to the fact that he said it does not make any difference about the tuyere because it does. Suppose he'd run that 1 to 25? He could not have got along very far with that. You can do that with a little heat. We want to melt 50 or 60 tons and we want to avoid a slag and want to keep our cupola clean.

The author mentioned continuous tuyeres. When you make a continuous tuyere you have a continuous opening all around your cupola; you will find when you get up to the limit of your cupola, it will bung up and bridge over, but if you leave a place between your tuyeres so there is some place for the slag to run down between the tuyeres, you can run all day.

W. V. BERRY: I believe the general conclusion all foundrymen have come to is that we should judge by volume and not by pressure. Now, in the case of this experimment we use a 32-inch cupola. The size of the tuyere in a 32-inch cupola does not materially affect the melting rate, for this reason, it makes no particular difference whether that tuyere area is large or small, for the reason that we have just a small cross sectional area and our air will usually go into that in a fairly uniform manner.

Let us take the case of, say, a 60 or 70-inch cupola; in that case I think the tuyere area is vitally important to that cupola, for this reason: in melting in a cupola we must melt as uniformly as possible. The volume of course is what gives us our melting speed and our temperature. Now, take the pressure; if we will disregard whether that pressure runs at 6 ounces or 12 ounces, but we will cut down the size of the tuyere or increase the size to get the proper penetration of the blast. Take, for instance, a cupola where we are melting malleable iron. I have found through experience that our tuyere area is vitally important there so that we can get the blast to penetrate properly to the center and still get a distribution of the blast at the shell. I have used a large tuyere area and found that I did not have pressure enough, did not get the blast to the center of that cupola; therefore, I had chilled iron which, in the case of a large foundry would cool too quickly and the result was we had a lot of castings that were misrun. The same thing is true when using a tuyere that is too small; we get too much of the blast at the center and therefore have cold spots around the lining of that cupola and part of the iron coming down is cold and therefore it is not satisfactory.

Speaking of the continuous tuyere, it is my experience that the continuous tuyere has been the ideal tuyere to use. The simple reason is that all the blast gets from the shell into the cupola and the more equally distributed that blast is the better melting conditions we have. This is because we have no cold spots whatever and we are making an effort to allow that cupola to melt hot at all spots.

Now we will probably find, for instance, in some of the cupolas we have one blast height leading into it and in some we have two blast heights. In each case each tuyere will take a different volume of air. Sometimes it is necessary to observe closely all changes in different tuyeres and make them of a little different area and keep every tuyere melting hot.

In regard to the melting zone, the smaller it is the better. In some cupolas we will find a melting zone varying from a foot to three feet, which is bad practice; melting in the lower section of that melting zone

means oxidized iron; melting in the higher portion means an iron that is high in sulphur and comes out of the tap hole cold. I believe we should find the hottest spot in that cupola and try to melt all iron charges in that one particular space; therefore, if you confine your melting zone to a space of twelve inches, you have the best results and have the hottest iron. I agree with Dr. Moldenke in regard to tuyere area. Take a small cupola, 33 or 34 inches; your tuyere area usually will run 1 to 4. Getting up into the larger cupolas, say 60 or 72 up to 84 inches, the usual tuyere area will be about 1 to 10, so that we can get more penetration of that blast to the center and melt in a more uniform manner.

S. J. Felton: I disagree with this last speaker in respect to melting in that highest temperature zone. I went into that in some detail in my first cupola paper some two years ago. If you melt in that hot zone, you keep your sulphur down but get just as high a temperature if you melt above that zone. That excessive temperature is used to melt the iron; it does not superheat it very much. If you melt above it, it has got to drop down through that zone. I made a chart one time showing tapping temperatures, oxidation losses, humidity and everything that enters into that stack and I say it is a very fortunate thing that we can melt above that zone and get just as hot metal. When you melt a little higher you need a little excess coke.

I certainly appreciate what Mr. Grennan has done on cupola experiments. When I published my first paper, my chief premise was that iron melted high in the stack. That was the biggest guess I had to make. I assumed it had to from the results I got, and I knew that if it melted at a lower temperature it had to melt higher in the stack, and Mr. Grennan came out with his results at the same time, showing that iron did melt 30 or 40 inches in the stack.

Mr. Grennan brought out the very pertinent point that the size of the pieces had sometimes as much effect as the melting point. In the average foundry processes, the size stays about the same and if you use too big pieces of chilled pig, you cannot reach that high temperature, or if you use pieces too small, you cannot get the proper temperature.

In respect to that continuous tuyere there is a patented tuyere on the market, the Zipler, but I do not think you will find that it covers up the slag in a long heat.

H. W. Hyde: I am glad you mentioned the Zipler tuyere, because I have them in my cupola. It is a continuous tuyere with six auxiliaries which are brought in about two feet above the main tuyere. I stopped up the auxiliary tuyere; could find no difference in the melting temperature, but I did find a difference in the amount of iron melted with the same blast. I also found with the upper tuyeres in operation an erosion all around those tuyeres and it looked to me as if the pressure coming into those tuyeres right at the hot spot forces the gases back against the

lining which caused the erosion. With the upper tuyeres plugged up, we found that the erosion was dropping about ten inches below the point of operation of the double tuyere. I would like to hear some more discussion on this double tuyere. I do not like them, but we have to use them.

J. D. STODDARD: I would like to ask whether this cupola at Ann Arbor was operated with a single or double row of tuyeres? That is a very much mooted question and there are a great many who do not agree. You will find many foundries still operating with two rows of tuyeres. Now my observation is that it is an expensive proposition and there is nothing to be gained by it, providing that the area of the double row of tuyeres remain the same when the top row is closed; in other words, when you close the top row of tuyeres, you should not increase the lower row, and you will always get improved conditions.

I would say I believe Mr. Grennan is correct in his final conclusions regarding the area of an ideal tuyere; for ordinary foundry work about 1 to 4 is a very good ratio. I rather disapprove of the continuous tuyere, the box tuyere with small spaces between the tuyere.

Furthermore, I want to bring out the point that this experiment with comparatively high silicon mixtures is not the way that these experiments should be conducted, in my judgment. I think the gentleman who is melting malleable iron in a cupola is in a better position to judge the effect than the man who is running the ordinary mixture, because the malleable or car wheel mixtures are so much more sensitive to changes of that nature and if there is an oxidation it is more easily detected.

H. RAYNER: We have had experience with a single row and double row of tuyeres, and our experience has been that with the double row of tuyeres we get about 20 per cent greater production. We tried the same thing Mr. Stoddard mentioned we should do if we took the upper row off, that is, add the area on to the lower row. On these cupolas which were 43 inches, supposed to be 48, we found that we could get 8 tons per hour with the lower row only with a ratio of about 1 to 3½, and after putting the upper row back into operation again we could get 12 tons per hour, running all day. We found that it was impossible with the lower row to run all day under the same condition, and with the upper row we could only run about 3 or 4 hours. At the time they were closed up we ran the test for about 6 days. The reason for running the test was that certain people told us the single row would be better than the double row.

J. D. STODDARD: Mr. Rayner's experience is opposite to mine. It is difficult for me to believe that you get 20 per cent greater production by using two rows of tuyeres of the same area than if you used one. I have personally been responsible for the closing up of the upper row of tuyeres in a hundred or more stacks during the time I have been actively interested in cupola operation, and I was able to get fully as great a tonnage per hour as before, providing the proper area was placed in the lower

row of tuyeres. The expense of operating a cupola with the upper row of tuyeres is increased. As soon as you put in the bed of coke you have to maintain the same height of coke above those tuyeres as above the lower, in order to get proper operating conditions, and I cannot see any advantage in blowing a small volume of air into the upper melting zone of a cupola. It seems to me that it is the wrong idea itself. When he speaks of melting 12 tons an hour in a 43-inch stack, I do not believe there are very many here who are able to get any such tonnage as that. I have not been able to do it and get hot iron and I have not been able to get 8 tons an hour out of a 41-inch stack. If you get 10 tons an hour out of a 48-inch stack with the ordinary foundry conditions, you are doing mighty well.

M. F. BEETHUM: I think Mr. Rayner is absolutely right on this two rows of tuyeres for a long heat. I do not believe Mr. Stoddard mentioned his heat. I found a few hundred cases of long heats and they all used two rows of tuyeres. They find that they do not get the changing in the cupola on long heats with two rows where they do with one. You will find that the Singer plant, at Elizabethport, N. J., uses three rows of tuyeres and they say they get better iron. Of course, it takes more coke.

I might comment a little on Mr. Grennan's test. This seems to be an ideal test condition, but I do not believe it is an ideal foundry operating condition. The length of the heat is very short. I believe a foundry that was going to melt tonnage like this would not run every day, 50 minutes or an hour. They would run two times a week, it would be more economical. To use the 40 to 1 tuyere ration on a two to three hour heat would not be practical. I believe while your pressure inside the cupola may be the same, the velocity of the air coming through the tuyeres is very much greater; it has to be, and this high velocity air is bound to chill your slag and cause bridging.

I am glad the author comes out for 1 to 4 tuyere ratio, which I think is perfect. I do not see any use of changing that Where he says foundrymen may discard the idea that small tuyeres will have any marked influence on melting, I do not agree with him. You will find in small foundries that very few of them that have a variable speed motor on the blower. About one out of a hundred has a variable speed motor.

Foundries get to making their own tuyeres and owing to the convenience of making their patterns without the two ribs across them which are originally inserted to divide the blast coming through the tuyere and also to support this cover plate on the tuyere. If you leave the ribs out the cover plate will sag and your area inside the tuyere will become less and you get into trouble.

If foundrymen read this where it says, "Foundrymen may discard the idea that small tuyeres will have any marked influence on melting. If

their cupola is not working regularly they need not blame small tuyeres for their trouble. It might be advisable to use large tuyeres but within the limits of the sizes in use no foundryman is justified in changing his cupola tuyeres except at such convenient times as when relining the cupola," they won't know what to do about it. It may be all right with a variable speed motor, but I would like to see further tests run under real foundry conditions.

J. GRENNAN: I would like to answer the gentleman from Detroit in regard to the tuyeres. My viewpoint is a little different from his. The stock in descending brushes against the side of the cupola and it is kept open so there is a greater rate of passage of the gases along the side of the stack. That stack also gets hot and reflects heat back into the stock, so the outside of the stack or along the wall heats faster than the center. Introducing upper tuyeres makes it heat still faster. From a metallurgical standpoint, I would say the upper tuyere is undesirable; from an economical standpoint, if you can get a greater rate of melting with upper tuyeres why then balance your decreased cost against your metallurgical results and decide what you want for yourself. In regard to using a variable speed motor and a positive blower, this gives us ideal operating conditions. I think that is covered in the paper satisfactorily, but keeping the other conditions constant and changing the tuyeres only is what I was talking about. If you have a fan, increase the pressure and you are going to increase your volume so that a fan will give varying conditions.

In regard to penetration of blast in large cupolas as brought out by Mr. Berry, I would like to state that we could get no signs of change in penetration through 16 inches of stock by changing tuyeres from a ratio of 4 to 1 to a ratio of 41 to 1, it does not seem reasonable to expect a penetration due to nozzle effect through 36 inches of stock due to a difference in tuyere sizes used in the cupola at the present time. It also seems logical that penetration of blast due to nozzle effect would burn tunnels in fuel bed where blast penetrated.

Desulphurization of Ferrous Metals

By George A. Drysdale,* Cleveland, Ohio

During the past few years considerable thought has been given and experimental work carried on, to improve the production of steel, malleable and gray iron castings. The ultimate aim being to lessen the cost of production and raise the quality and physical properties of the metal.

In the production of iron and steel castings a number of more or less complicated problems are involved, such as the selection of raw materials, sand, pig iron, coke, flux, etc., also the mixing, melting, molding and heat treating problems. Although each is distinct, yet collectively, they control the final results.

Iron and Sulphur

In dealing with ferrous metal, a good deal of the trouble encountered is caused by the action of the sulphur and oxides (which the metal contains) when poured into the mold, and its subsequent action during the solidification period. The action of the sulphur on cast iron and steel is very detrimental. It causes excessive shrinkage, hardness, porosity, blow holes, etc. The effect of using a sodium compound as a desulphurizer and purifier, in the melting of high sulphur iron, produces softer iron and eliminates hard spots, excessive shrinkage, porosity and surface scale. The resulting castings tend to give higher physical properties and lower Brinell hardness. Iron and sulphur combine readily to form iron sulphide (FeS) which is a hard brittle substance with a fairly high melting temperature. When present in molten iron it solidifies last and between the separate crystals of iron and thus weakens the metal. Even with small quantities present, the metal is more or less affected. Sulphur will segregate more than any other element, although sulphide of iron which is soluble in molten iron does not segregate as much as manganese sulphide which is not soluble in the molten iron. Blow holes in pig iron and cast iron fractures usually found near the surface are associated by most

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foundrymen with high sulphur, however new opinions have been formed by several metallurgists and chemists, that these are primarily due to oxidation. It is customary to allow about 0.010 percent additional silicon for every 0.01 percent of sulphur above the usual percentages, varying between 0.08 and 0.12 in order to obtain the usual softness as the bad effects of sulphur show up in the rapid machining of thin castings.

Iron and Oxygen

The bad effects of oxygen in cast iron are well known facts, such as the raising of the temperature at which a metal usually sets, which shortens the life of the metal. Oxidized iron sets quicker and prevents proper feeding of castings from the gates and risers. It results in interior shrinkages usually found close to the gates or risers, and adds to the percent of bad castings. Oxidized iron is usually associated with increased combined carbon which means harder castings, especially in light sections, and causes trouble for the machine shops. The shrinkage is also greater and this sometimes mean cracked castings. Experiments have shown that there is a reaction between carbon and oxygen which forms a carbon monoxide gas. It is possible that this formation will take place within a mold which is being poured and oftimes accounts for pin holes and gas pockets in the cast metals.

Great care being exercised in the purchasing of the raw materials to conform with rigid specifications, invariably necessitates paying a high price for such materials. It narrows the source of supply which often places the foundryman in an embarrassing position.

Fluxing of Metals Important

During the past few years the fluxing of the molten metals has become of extreme importance, as a majority of foundrymen believe much of their foundry troubles can be traced to the raw materials and their melting conditions. At the present time the study of fluxes and sand is paramount in the foundry industry. This paper deals with the desulphurization and purification problems only.

Limestone or calcium carbonate $CaCo_3$ has heretofore been regarded as the superior flux, and often used with additions of fluorspar, ferromanganese, etc., for purification and desulphurization, but with such materials, only partially successful results have been obtained. In other words, such materials are not vigorous enough in their ability to remove sulphur, oxides, etc., from the metal, especially when melted in the cupola furnace. Where the metal is melted in direct contact with the fuel, the problem of desulphurization and oxidation becomes more acute than where the metal is melted in an air or reverberatory furnace where only the flames and gases of the fuel come in contact with the molten mass. For this reason cupola iron has been regarded as an inferior product and usually commands a lower price.

Limestone and Viscous Slag

Limestone (calcium carbonate) has the further disadvantage of forming a viscous slag and when the molten iron or steel is treated with this material its desulphurizing influence is counteracted by its viscosity, which renders the slag less active as a purifying agent. Calcium carbonate has a greater affinity for silicon than it has for sulphur, consequently the calcium carbonate will first form calcium silicate and thus reduce the amount of calcium available to eliminate the sulphur.

A number of secondary fluxes have been used, such as borax, sodium nitrate, magnesium and potassium salts, etc. It has been found that borax has a strong affinity for metallic oxides and holds them in solution in the slag formed, but is of little value as a desulphurizer.

The desulphurizing effect of the slag is proportional, not only to its basicity but also to its fluidity in almost an equal degree, so that increasing the percentage of limestone, it has greater desulphurizing influences—counteracted by its viscosity. Therefore with large percentages of limestone the desulphurizing influence is nullified.

After a great deal of experimental work has been done with the various fluxes when used under various conditions in the cupola furnace, air furnace and ladle, alkaline salts have been found to give the most satisfactory results in the purification and desulphurization of ferrous metals. The use of sodium carbon-

ate in combinations with the more vigorous alkalies, such as sodium and potassium hydroxide and other beneficial ingredients, now form a series of fluxing compounds which are being used to great advantage in purifying iron and steel.

To use such fluxing compounds to their best advantage, it is essential that the chemist, metallurgist and foundryman should have a good working knowledge of their action in the melting process, also their advantages and disadvantages. The object of fluxing a cupola furnace is to get rid of the impurities formed in melting the iron, such as sand or silica from the sand pig iron, scrap iron and ash from the fuel. Basic and silicious materials must be present in the correct amounts, to aid in the formation of a satisfactory slag and must be easily fusible at the temperature of the furnace in melting iron.

Use of Sodium Compound

Flux carrying sodium carbonate as a desulphurizer and purifier, melts at the relatively low temperature of 858 degrees Cent. which is below the melting point of iron. This flux has a low specific gravity and high fluidity which prevent it from being enmeshed in the metal and enables it to rise readily to the top and carry impurities with it. Sodium compound has the further advantage of giving up carbon dioxide freely at the temperature of molten iron and steel and this causes boiling of the molten metal, bringing impurities and injurious gases to the top. The carbon dioxide is not injurious to the metal, because it is practically an inert gas at the temperature range of molten iron and steel.

The sodium compound does not start to decompose until it reaches the approximate temperature of molten iron and when decomposition occurs, the sodium exists for a brief interval in the nascent state and owing to its great affinity for sulphur, it forms sodium sulphides which are stable compounds. These rise to the surface thereby desulphurizing the metal. So long as there is sodium present and sulphur available in the metal, the greater affinity of the sodium for sulphur than for silicon and phosphorous results in the silicon and phosphorous being left in the metal practically undisturbed.

Further, sodium compound, because of its fluidity and ability readily to separate from the metal and rise to the surface, carries

with it impurities, such as oxides, which are known to make the metal more sluggish. The sodium compound makes the metal more fluid, thus giving the occluded gases better opportunity to escape. This results in reducing blow-holes in the finished casting and permits the use of the cheaper high-sulphur iron and more scrap metal in the melting stock.

Sodium Compound in the Cupola Furnace

A number of interesting tests have been made to ascertain the actual desulphurization of the metal with the sodium base compound, when used in the cupola furnace, air furnace, and ladle. It has been found that when using the compound in the cupola furnace, that the most satisfactory results are obtained by adding certain proportions of the sodium carbonate compound to the limestone and placing them on the several coke charges. The actual amount of sodium compound and limestone will depend upon the viscosity of the slag formed and the amount of desulphurization required. As a general rule 5 to 10 pounds of the sodium compound is used for every ton of iron melted, and maximum amount for cupola mixtures carrying large percentages (60-80 percent) of scrap and pig iron running over 0.050 percent in sulphur or where a high reduction in sulphur is required. When melting iron in the cupola furnace it has been demonstrated that the addition of sodium carbonate compounds to the iron charges, does not in any way injure the lining of the cupola, as long as its alkalinity is not excessive. Such additions give a clean drop at the end of the heat which is a material saving in time and labor, and eliminates to a great extent the laborious work of "chipping out the cupola."

In general foundry practice, when limestone is used as a flux, it is added after a number of charges of iron have been tapped from the furnace or when sufficient slag forms to interfere with melting process. The first iron which always runs high in sulphur, having taken up an excess of this element (sulphur) from the coke bed, is regarded as *off iron* and used for an inferior grade of castings. With the use of sodium carbonate compound, it is essential to use the limestone and sodium compound with the first charge of iron and on each of the succeeding charges—owing to

the higher absorption of sulphur at the first of the heat, larger proportions of the sodium compound should be used so as to make the heat more uniform and eliminate any off iron. To the first two charges it is advisable to add double the quantity of sodium compound, which would be from 10 to 20 pounds.

Sodium Compound in the Air Furnace and Ladle

When the sodium carbonate compound is to be used in the air furnace, it has been found advantageous to add the compound after the first slagging, in quantities ranging from 5 to 10 pounds for every ton (2000 pounds) of iron melted, and stir thoroughly so as to make the chemical action as uniform as possible throughout the molten mass.

When treating the molten iron in the ladle, with a sodium compound, it is advisable to add the compound in the proportion of 5 to 10 pounds for every ton of iron melted. Place the compound in the bottom of the ladle and tap the iron on to it—stir thoroughly and after the molten mass becomes quiet, add either limestone, burned lime or chalk in the powdered form, to the impurities which form on the surface to make the slag more viscous. Thus making an easier separation of the metal and slag when pouring.

A spray of water may be used to good advantage for such a purpose. It decomposes the sodium sulphide, the sulphur passing off as SO_2 in a gaseous form which allows the slag to take up additional sulphur from the molten iron.

Tests have shown that the desulphurization of the metal is not the only good results of sodium compound when used as a flux. The deoxidizing and purifying features are also of great importance in producing a superior grade of metal. A true flux must be prepared in a scientific manner with a full knowledge of its chemical action in the melting of the different metals. Otherwise the results cannot be satisfactory.

Ladle Tests Made

A number of interesting tests have been made with sodium compound in the cupola and ladle, to determine the actual reduction of sulphur in the metal. A ladle test was made at the Taylor & Boggis Foundry, Cleveland, O., with a sodium compound con-

taining sodium hydroxide and a catalytic agent. The tests were conducted by Robert R. Snow, foundry superintendent.

To obtain as high a percentage of sulphur as possible, a bed charge of iron was made up of 1700 pounds of scrap iron and 300 pounds of pig iron. Three sets of similar test bars were prepared. A was poured from the metal before the treatment, B after treatment, and C after the second treatment. The second treatment was carried out to ascertain the further loss of sulphur, if any. Chemical analysis of the three test bars, gave the results shown in Table 1.

Tests made with the sodium flux in the cupola and air furnace have also proven very satisfactory although the amount of desulphurization does not run as high as when the iron is treated in the ladle. The proportions are approximately as follows:

Desulphurization in the ladle . . . . 0.040 percent
Desulphurization in air furnace . . . 0.020 percent
Desulphurization in cupola furnace . . 0.030 percent

The greater the sulphur content in the molten metal, the higher will be the percentage of reduction and vice versa.

Table I

Element	Percentage A	B	C
Silicon	2.20	2.16	2.05
Sulphur	0.106	0.046	0.038
Phosphorous	0.286	0.328	0.340
Manganese	0.360	0.370	0.350
Combined Carbon	0.650	0.580	0.570
Graphite Carbon	2.600	2.750	2.740

After treatment with the sodium compound, the reduction in sulphur of B to A is 0.060 per cent and of C to A 0.068 per cent, the other metalloids remaining practically the same. Total reduction in sulphur 0.060 per cent.

Result of Cupola Tests

A test was also made at the same plant by treating a soft gray iron mixture with the sodium compound in a cupola furnace. The chemical analysis of the test bars poured from the mixture before treatment, gave an analysis showing silicon 3.37 percent, sulphur .083 percent, phosphorus .509 percent and manganese .58 per cent.

The same mixture was used for the test heat and 14 pounds of compound used on the bed charge (3000 pounds) and 10 pounds

on the regular charges (2000 pounds). Test bars were poured from the first, middle and last of the heat—or 30 minutes apart, gave the following chemical analysis.

1. Test Bar-Silicon 2.98, Sulphur .060, Phos. .485, Mang. 56
2. Test Bar-Silicon 2.97, Sulphur .059, Phos. .523, Mang. .54
3. Test Bar-Silicon 3.15, Sulphur .066, Phos. .531, Mang. .48

Five charges were used at the last of the heat, without any additional of the sodium compound, there being enough of the compound remaining in the cupola to give the following results:

Silicon	3.28 percent
Sulphur	.070 percent
Phosphorus	.552 percent
Manganese	.490 percent

It will be noted that the reduction in sulphur content in the treated metal, taking the average sulphur of bars 1, 2 and 3 is 0.021 percent and the difference between the untreated metal and the test bar poured from the last five charges is 0.013 percent.

SUPPLEMENT

Since the Issue of This Reprint the Following Cupola Tests Have Been Made With the Desulphurizing Compound:

Tests were conducted at the Diamond Match Company, Barberton, Ohio, to determine if the use of a sodium compound was in any way detrimental to the lining of the cupola and also the actual desulphurization of the iron by its use. A cupola furnace was used in melting the iron. The diameter of the shell was 50 inches lined down to 38 inches. The average melt was 12,000 pounds per heat. The coke used for fuel was a good grade retort oven foundry coke. The iron mixture was composed of 50 per cent pig iron and 50 per cent scrap. The melting ratio of coke to iron was 1 to 9. Following is a synopsis of the tests covering a period of eight days:

Aug. 26-27—Twenty-five pounds of the compound was used on the first charge of coke and 15 pounds on the following charges. No limestone used.

Aug. 28-29, 31-Sept. 1—Fifteen pounds of the compound was used on the first charge and 10 pounds on the following charges. No limestone used.

Sept. 2-3—Twenty pounds of compound was used on all charges with 40 pounds of limestone on each charge. All iron charges were 2,000 pounds or 1 ton.

The cupola was carefully examined from time to time during the tests and no detrimental action was apparent on the lining by its use. As to the desulphurization—in the tests bars poured from the first, middle and last of the several heats—the following figures show a decided reduction in the sulphur contents, with an increase in transverse strength.

General average—untreated bars.....0.078 per cent
General average—treated bars.....0.064 per cent

Reduction .....0.014 per cent

or 18 per cent of the total sulphur present in the iron.

TRANSVERSE STRENGTH INCREASE

Test bars 1 inch square 12 inches between knives, dead load at center.

General average transverse strength untreated bars—pounds per square inch	2,436
General average transverse strength treated bars—pounds per square inch	2,797
Average increase in treated bars	361

A similar test was made in the malleable foundry of the Pittsburgh Valve & Fittings Company, Barberton, Ohio, in a cupola furnace, lined down to 44 inches and melting on an average 24,000 pounds of iron or 12 tons to the heat. Retort oven foundry coke was used as fuel and a high grade limestone as a flux. The iron melted was composed of 20 per cent pig iron and 80 per cent scrap, (40 per cent gates, sprues and returns and 40 per cent foreign scrap—railroad malleables). The tests covered a period of 12 days. Prior to the tests, the cupola was relined from the charging door to the top of the tuyeres. The first test covering a period of 2 days, Aug. 17 and 18, to determine the actual "wear and tear" on the lining, no sodium compound being used. The second test covering a period of 10 days, was to determine the action of

the compound on the cupola bricks. A careful examination was made after each heat, which showed that the compound did not have any detrimental effect on the lining. The tests also demonstrated that the compound had a tendency to form a glaze on the cupola bricks in the melting zone, which was beneficial in producing a clean drop at the end of each heat.

The following table shows the sulphur determinations made prior to the desulphurization tests. Sample drillings were obtained for lugs poured at the first, middle and last of the heat and mixed for chemical analysis:

Date Poured	Per Cent Sulphur
8- 3-25	.109
8- 4-25	.121
8- 5-25	.120
8- 6-25	.109
8-10-25	.107
8-11-25	.113
8-12-25	.109
8-13-25	.108
8-17-25	.104
8-18-25	.111

Average Sulphur 0.111%

The desulphurization tests covered 9 heats. During these tests lugs were poured from the first, middle and last of each heat the same as in the first instance, and drillings obtained from each lug for sulphur determinations so as to determine the variation of sulphur in the different parts of the heat.

Date Poured	Lug 1	Lug 2	Lug 3	Average
8-19-25	.108	.093	.090	.097
8-20-25	.099	.091	.093	.095
8-21-25	.113	.068	.071	.089
8-25-25	.105	.086	.077	.089
8-26-25	.106	.097	.095	.099
8-27-25	.098	.093	.096	.095
8-31-25	.102	.093	.091	.095
9- 1-25	.107	.083	.079	.090
9- 2-25	.088	.066	.090	.081
General averages	.103	.086	.087	.092
Sulphur reduction	.008	.025	.024	.019
Actual sulphur removed.	7 1/5%	22½%	22 3/5%	17%

It may be interesting to note on the final test, poured 9-2-25, that the sulphur determinations were as follows: 0.088, 0.066, and 0.090, or an average of 0.081 per cent. The two following heats without the use of the desulphurizer, gave an average of 0.123 and 0.120 per cent of sulphur respectively. This shows an increase of 0.041 per cent of sulphur, making a total gain of 51 per cent in that element.

The above results may be regarded as an average of tests made in several foundries producing different grades of castings.

Experimental work has been conducted in the use of the electric furnace for desulphurization and purification of cast iron. While this is a very effective method it is also expensive and retards production, however, we are not discussing the merit of the electric furnace or otherwise as this paper deals entirely with a cheap and effective way of desulphurizing and deoxidizing in types of melting furnaces, other than the electric furnace.

The study of the scientific fluxing of metals may still be regarded as in its infancy. Vast improvements along these lines may be looked forward to during the next few years, owing to the careful and thorough experimental work performed by the chemist and metallurgist, and the open mindedness of the majority of foundrymen whose chief object is to gain a broader knowledge along their several lines of endeavor.

DISCUSSION

CHAIRMAN W. J. KIHN: The particular company with which I am connected has been experimenting along the line of using a desulphurizer and it is apparent that there is a great deal of value in this desulphurization proposition, particularly if the price of scrap iron ever gets back to some sort of reasonable relation to the price of pig iron. We have very easily secured 30 per cent reduction in sulphur content in the ladle, and in open hearth operation have done even better than that. The experiments so far, however, are of a preliminary nature. The worst feature we have found in the Worthington Pump Company has been the handling of the very fluid slag in the ordinary type of ladle. This is not true when using fluorspar, however; and if anyone has had additional experience in the handling of that slag in the ladle which is the easiest and

simplest way to handle the desulphurizing, I personally would be very much interested to hear it. I realize that a teapot spout ladle will aid materially, but I am hoping against hope that we will find some way to thicken that slag so as to skim it off and not cause us trouble in our casting operations.

H. RAYNER: Our experience with this soda ash would be of interest to the members. In 1921 we found that we were handicapped in our molding by having a large stock of inferior coke which we had to use up when we resumed production and we had oxidizing troubles in our cupola and someone suggested that we use a soda ash in the ladle. We used it in the ladle from 1921 until we were able to get a better grade of coke. Our sulphur difficulty disappeared as soon as we got a better grade of coke. By getting a better grade of coke we found after two or three years' investigation that the coke companies were giving us a coke coked somewhere between 15 and 16 hours during the previous period, and in 1922 we got 36 hour coke and had no oxidizing trouble whatever. While we were using soda ash we had that trouble.

Dr. Moldenke says that if you use slack lime it will thicken up the slag, and he disapproves of the practice of throwing sand on it; he says that that is poor practice, but we found that even using the lime did not satisfy our requirements, so we went to the teapot spout ladle and it was very satisfactory, but expensive. We had to build the spout right in the ladle and leave a hole 4 by 6 inches at the bottom of the ladle, and we found that the slats fell away. We would have had to come to a special ladle if we had not received the better grade of coke, which enabled us to get away from the difficulty.

We found that the sulphur did decrease between 20 and 30 per cent, also that the castings were softer, and as near as we could tell, just as strong. In fact we did not find any detrimental results in regard to strength or any similar property. We did not investigate for any of those things; all we were trying to do was to get away from the difficulty due to oxidization due to the coke. Another point, we used a larger percentage of scrap, practically all we could absorb, and it amounted sometimes to as high as 50 or 60 per cent, with a small quantity of steel added, as well. We know that we would not have been able to use that amount of scrap if we had not added the sodium carbonate. Our practice has improved and we do not have the scrap now to melt, and therefore do not need the desulphurizer.

H. W. HYATT: I tried out the desulphurizer and ran into some difficult with slag on the ladle. We had no teapot spout, and found that very fine gangway sand, burned sand if put on to the slag and stirred in well would stiffen it enough so that it could be skimmed off completely I found the action was practically the same as lime. Mr. Rayner speaks

of Dr. Moldenke disapproving of the use of sand. I wonder what is the basis of that objection.

H. RAYNER: I do not remember what the disapproval was based on at the time, but we did use the sand and got away with it. Another thing we used was mill scale, and we found that it was better than the sand.

R. S. MACPHERRAN: If you add silica, the sodium will mix with the silica and the sulphur will go right back into the cast iron. In our plant it made a nasty operation right in the middle of the shop. We took out some twenty to fifty thousandths of sulphur, but it involved a three or four minute delay and was a very bad, nasty skimming operation, and as the furnaces got better in their sulphur practice, we dropped it.

W. V. BERRY: Mc. MacPherran states that Dr. Moldenke's objection to sand was that it contained a silica composition that would unite with the sodium and turn the sulphur back into the metal; that is correct, but it has a greater affinity for the sodium than for the silicon and therefore you can use dry sand from the gangway without resulphurizing the metal. It is true that sulphur will form a very thin, fluid slag; the only way you can overcome this condition is to use powdered lime or dry powdered sand; a spray of water will do it. That is the reason this field opens up development work in the use of a sodium compound right in the cupola; using it in the cupola, satisfactory results can be obtained in desulphurization and deoxidation, and the metal comes from the spout nice and clean, therefore the place to use this desulphurizer would be in the cupola or air furnace or open heart furnace.

S. R. ROBINSON: We have a steel foundry in our converter works and we want a real low sulphur steel. When you talk of 20 per cent it does not interest us at all; we want to get it down below nought five for steel castings and an alkali compound has become of great importance to the converter steel foundry. The whole bugbear of converter steel was the high sulphur and now we have that under control. By using an alkali compound containing the sodium and sodium hydroxide we can cut the sulphur from naught nine down as low as nought thirty-five and nought four, which makes as good steel as any of the acid open hearth furnaces or acid electric furnaces, in so far as sulphur goes. This means a ladle addition. We have not been able to get any such reduction with a cupola addition.

One difficulty we have with the ladle addition is the fumes. We have installed exhaust fans or hoods with a fan over the iron ladle and have been able to carry out some of them that way, but still have some trouble, not that the fumes are poisonous, the men might think so, but they are only irritating. In the summer, if a man is sweating, they might irritate him around his neckband and eyes and make a smarting, but they aren't poisonous. Sodium carbonate is not poisonous; it is of the same family as our baking soda at home.

This is of vital importance and it seems to me there ought to be more study and more thought put on it in cast iron. Some say, "Well, we don't care, we want .11 and .12 sulphur in some forms of iron." I wonder what would they get if they got that down to nought four and could cut the silicon, what kind of a product would they get? It is an intensely interesting subject to investigate.

S. J. FELTON: I think most of you are familiar with desulphurization in the case of cast iron in the basic electric furnace. I want to offer a suggestion or get someone's viewpoint on the possibility of mixing a little fluorspar with the sand that goes on that ladle. That would overcome the objection, if there is such an objection, of the sulphur going back into the bath, and although sulphur thins out a basic slag, with the acid slag I think it would have a coagulating effect which should help that process.

F. H. GULDNER: Our company has done considerable work with sodium alkalis to desulphurize iron. The car wheel industry has furnished car wheels to a sulphur specification and from that standpoint we are very much interested in this proposition. Several important phases have come up in connection with this discussion. One I want to call attention to, but the case is not about poisoning.

When you purchase soda ash as such, or anything it enters into, the soda ash people will usually say it contains a certain percentage of sodium dioxide. This, as you know, is a very poisonous gas, and although it may not be there in very large quantities, yet its presence is poisonous. The same way with sulphur dioxide; if you have ever gotten around these furnaces where they are sweating with sulphur compound you can smell the old familiar sulphur match, it is there as SO_2 and sodium carbonate in dissociating gives off CO_2, which is poisonous only in large quantities, but in large quantities you get the poisoning. You get it in your residences when the atmosphere becomes polluated with CO_2, then there is a possibility of carbon monoxide being there, which is intensely poisonous.

I want to call your attention to the fact that I know in my own experience of several cases where we have heard of poisoning, and in one case there were five men off at one time due to poisoning. That condition has been remedied by the installation of hoods and forced drafts. If you are doing long heats and have a poorly ventilated shop, then it is necessary to install these hoods and if you cannot get sufficient natural draft, you have to supplement it with forced draft. If you are running long heats, I would caution you to take particular care.

G. A. DRYSDALE: There has never been any complaint in regard to the gases which have arisen, but I may say that these tests have been in ladles from 1,000 pounds to 4,000 pounds, and I could not say in regard to larger amounts if it was continued indefinitely in the foundry. That

is one advantage of melting it in the cupola, you do not have to have those troubles, but there has never been any complaint made about the gases which, apparently, have not been noticed.

CHAIRMAN KIHN: I wonder if anyone has had any experience in desulphurizing through fluorspar?

H. RAYNER: We tried fluorspar and that was one of the reasons we had to hunt for soda ash. It gave a very strong gas which we thought was fluorine, and we stopped the use of fluorspar before we had a chance to tell whether it was any good or not.

S. J. FELTON: We used fluorspar in large quantities around open hearth furnaces. I do not know whether any man has ever succumbed from the effect or not.

F. J. GRONDIE: I would like to ask a question on a point of information. We have ladles as high as 16 tons, and I have a practice of putting over a ladle (instead of charcoal in trying to keep the heat in the ladle) siftings from coke ashes. We have a lot of salamanders and sift those ashes and use them to put over the iron in the ladle. I was wondering whether I was doing the iron any harm by doing that?

H. L. CAMPBEL.: It is generally assumed that in burning coke one-half of the sulphur goes into the ash and about half is removed in the gases of combustion, so it probably would be detrimental if the coke that you use in the salamanders is high in sulphur content. You probably get about half of the sulphur in the ash and if the coke is high in sulphur there may be a point there on the absorption of sulphur from that ash that you put on as a cover.

J. D. STODDARD: I would like to know if anyone here has had experience so that they can recommend the regular use of soda ash in a desulphurizing compound on the charges in the cupola the same as in limestone? I have always felt a little reluctant to add these things to the cupola for fear of an excess being used and detrimental effect on the lining of the cupola. Without some information from someone who has had an extended experience, I would hesitate to recommend to anyone the desirability of using that.

G. A. DRYSDALE: In part of the paper it gives a test made at the Pittsburgh Valve & Fittings Co. which covered a period of ten days. It goes into the desulphurization and also this question which was asked directly, does the use of the compound affect the acid lining of the cupola? For instance, on two days this compound was used alone. The cupola had been relined to start off and the cupola was carefully examined before the flux was used and ten days afterwards, and it was found that there was no detrimental effect whatever on the lining of the cupola.

J. M. SAMPSON: We used the combination for 15 months, and with very, very careful checking up of the cupola lining we cannot say that there is any increased wear. However, unless you have very careful control, using a very low silicon content in your limestone and have a number one man right there on the job every minute, you do not get the desulphurization that you possibly can get if you can keep everything going A number one.

F. H. GULDNER: I would like to ask Mr. Sampson about what amount of desulphurization you get in your cupola, that is in the ladle; giving the sulphur content to start with, and what you wind up with?

J. M. SAMPSON: You cannot beat good coke to start with. We figured with the very best operating conditions, to eliminate sulphur to the extent of normal sulphur picked up. In other words, we ordinarily would figure from .03 to .05 sometimes picked up and we also obtained an average of about .03 lower sulphur when we are using a particular material than when we were not using it. However, I want to caution everybody that it is extremely difficult to get this reduction in the cupola. In the ladle we had better experience, but on account of the class of work we had we found it very difficult to eliminate the very fine slag. On certain classes of work, however, we desulphurize in a small electric furnace. We hope possibly in the course of another year to have sufficient data to give you gentlemen something on this point.

J. D. STODDARD: I think this meeting ought not to be adjourned without a word of caution regarding the excessive fear that is existing (and which all of this discussion is apt to accentuate) in the minds of the foundrymen regarding sulphur. My original foundry experience was in a car wheel shop, and, as some of you know they do not fear sulphur in car wheels the way the ordinary foundryman does. In those days the sulphur in the car wheels which passed the specifications of the Master Car Builders' Association used to run .18 and over, frequently up to .2 per cent. There is no casting made in the industry probably that has to be subjected to more severe tests than car wheels; no castings made that have more severe usage and are of more importance. Now I understand after years of experimentation and agitation over the evils of high sulphur, the specifications of the Master Car Builders' Association require the sulphur not to exceed .14. Those figures are absolutely staggering to the average foundryman who is worried about his sulphur being too high when it gets up around .08 or .1 I believe that a great many evils attributed to sulphur can be, if proper investigation is made, traced to other improper practices in the cupola and foundry. You hear a great many people complain of blowholes due to excessive sulphur when the probabilities are that they are due to improper molding sand or improper cores or something that has to do with the making of the castings and the sulphur has nothing to do with it.

CHAIRMAN KIHN: I think Mr. Stoddard's remarks are very pertinent. If we succeed in running down this so-called sulphur bugbear, taking one more alibi away from our operating force, and locate the fault between sand, poor oil and desulphurization, I think the life of some of our operating forces would be considerably more interesting because their alibis will be somewhat reduced.

H. RAYNER: I agree with Mr. Stoddard. We had our sulphur as high as .18 and sometimes as high as .22 and made good castings and the cars are running yet. We found that with high sulphur and good melting conditions we get good iron. If the melting conditions are bad, then with high sulphur you do run into trouble.

R. S. MACPHERRAN: Mr. Sampson, how much soda ash do you use per ton of iron? I would like to ask also whether the pig iron casting was sand cast or chill cast?

MR. SAMPSON: I am sorry that I cannot answer that exactly. I will be glad to give you that information for your own use or anybody else's, however. We are charging the soda ash along with our limestone and the limestone is going in with the coke.

The Catalysis of the Graphitization of White Cast Iron by the Use of Carbon Monoxide Carbon Dioxide Mixtures When Applied Under Pressure

By Anson Hayes* and G. Clytus Scott,* Ames, Iowa

Some four years ago, when the study of graphitizing properties of white cast iron was taken up in our laboratory, the rather astonishing fact was brought to our attention that no systematic study of annealing oven atmospheres had been made. The possibilities of highly important influences, both on graphitizing rates as well as upon the physical properties of the material, seemed very great. The present study was undertaken as a part of the greater program of the investigation of influences of annealing oven atmospheres upon the production of malleable iron.

Honda and Murakami[1] suggested that carbon monoxide and carbon dioxide act as a catalyst in breaking down iron carbide. This conclusion comes very naturally from the fact that the process for carbonizing in the case hardening process is brought about to a large extent through the action of this gas mixture.

In the carbonizing process the carbon content of the case is determined by the fact that equilibrium is established between the carbon of the carbonizing pack and the dissolved carbon of the case through the action of the gaseous mixture of carbon monoxide and carbon dioxide.

The mechanism by which the above equilibrium is established may be illustrated in the following manner:

Consider the following chemical reactions:

$$(1)\quad 2\ CO = (C) + CO_2 \text{ and}$$
$$(2)\quad 2\ CO = C + CO_2$$

* Iowa State College.

[1] On Graphitization of Iron-Carbon Alloys, Jour. Iron and Steel Institute, Vol. 102, p. 287 (1920).

In these reactions the symbol (C) represents dissolved carbon in the metal while C represents pure carbon in the carbonizing pack.

If a large quantity of iron containing a small amount of dissolved carbon is heated in contact with either carbon monoxide or carbon dioxide an equilibrium condition will be reached in time. When this has been accomplished, analysis of the gas mixture will show it to be comparatively rich in carbon dioxide and poor in carbon monoxide. As the carbon content of the iron is increased, the gas mixture in equilibrium with it becomes richer in carbon monoxide and poorer in carbon dioxide, until when the iron is saturated with carbon at any one temperature and pressure, the compositions of these gases in equilibrium with the solution of carbon in iron and with the carbon of the pack are identical.

If the partial pressures of the gases and the equilibrium constant for the gases in contact with carbon dissolved in the iron be designated by the subscript I and those for the gases in equilibrium with carbon be indicated by the usual letter without the subscript, the expression for the mass law equilibrium constant for reaction (1) is

$$(3)\quad \frac{pI\text{-}CO_2}{p^2\text{-}I\text{-}CO} = K_I$$ and for reaction (2) is

$$(4)\quad \frac{pCO_2}{p_2CO} = K$$

Thus the above statements may be summarized by a consideration of K_I and K as follows: K_I is greater than K for all dissolved carbon contents of iron which are less than that necessary to produce saturation at any particular temperature. Thus K at 900 degrees Cent. is 3.48×10^{-2} when p is in atmosphere. For a total gas pressure of one atmosphere it represents a gas composition of 96.8 per cent carbon monoxide and 3.2 per cent carbon dioxide. K_I for all dissolved carbon contents less than that corresponding to saturation will be greater than K. This means that

at a pressure of one atmosphere the per cent carbon dioxide will be greater than that for the gases in equilibrium with carbon.

If some carbon and some iron not saturated with carbon be placed in a closed vessel and the vessel be filled with a mixture of carbon monoxide and carbon dioxide, the approach of the gas mixture in the vicinity of the carbon and in the vicinity of the iron to their respective values representing equilibrium will result

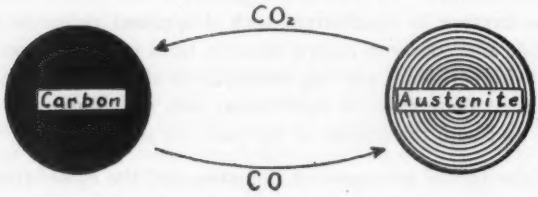

FIG. 1—GAS MIXTURE ACTING AS CARRIER OF CARBON IN CARBONIZING PROCESS

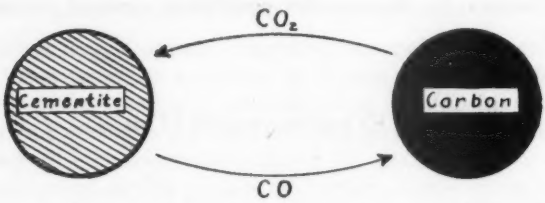

FIG. 2—GAS MIXTURE ACTING AS CARRIER OF CARBON IN GRAPHITIZING PROCESS

in a pressure gradient of carbon dioxide from the iron to the carbon and of the carbon monoxide from the carbon to the iron. This can readily be shown by taking values of K_I greater than 3.40×10^{-2} assuming a total pressure of one atmosphere and solving the equation $\frac{1-x}{x^2} = K_I$ where x is the partial pressure of the carbon monoxide in atmospheres. This may be diagrammatically represented by Fig. 1.

When this method of reasoning is applied to carbon and a metastable compound of carbon, such as (Fe_3C) cementite, the following result is obtained (see Fig. 2). This means that the gas mixture will act as a carrier of carbon from the iron carbide to the carbon. If again, as in reaction (1) we let (C) represent the carbon content of austenite in equilibrium with cementite at 900 degrees Cent. K_1 must be less than K. In short, this is the significance of the metastability of cementite at this temperature.

From the above treatment, it is to be expected that if iron containing carbon near the saturated value is readily permeable to this gas mixture of carbon monoxide and carbon dioxide, these gases should assist in the graphitizing process just as they do in that of carbonizing.

Ryder[2] has measured the permeability of iron to a number of gases, among them carbon monoxide, and although the gas was partially decomposed, as was to be expected, yet it diffused through the metal quite readily.

It is evident that limiting values for the rates at which the gas mixture of carbon monoxide and carbon dioxide could bring about carbonization or graphitization could be calculated if reliable rates of diffusion were available.

It was with these facts in mind that the present piece of work was undertaken. Because much more rapid progress was to be expected by such a method, a direct attempt at measuring the catalytic effect of this gas mixture was undertaken. Accordingly the apparatus shown in Fig. 3 was developed in which gas mixtures of varying ratios of carbon monoxide and carbon dioxide contents could be obtained and in which those mixtures could be applied to the sample at pressures up to 100 pounds per square inch and at temperatures up to 1000 degrees Cent. A description of this apparatus and the manner of operating it follows.

A is a carbon dioxide tank, B is a pressure gauge and C a control valve. D and H are drying chambers made from two inch black pipe eighteen inches long, threaded at both ends and fitted with caps. These chambers are filled with calcium chloride and phosphorus pentoxide. The carbon chamber E is made from three

[2]Electric Journal, Vol. 17, p. 161 (1920).

inch black pipe, three feet long, threaded at both ends and fitted with caps. This chamber is filled with carbon. The lower end is filled with loose gas carbon and the part exposed inside the muffle furnace F is packed with powdered wood charcoal or graphite. A thin layer of gas carbon is packed on top of this. This tube is filled only to the point at which it emerges from the furnace at the top. G is a chamber, similar in size and construction to D and H and is filled with a 35 per cent solution of potassium hydroxide

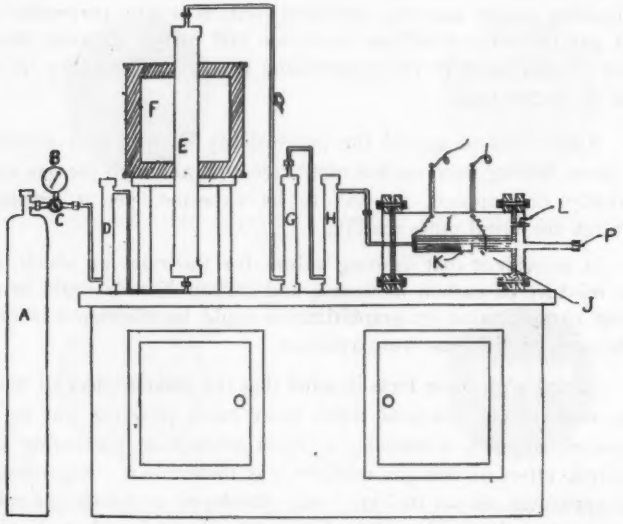

FIG. 3—APPARATUS FOR ANNEALING UNDER VARIOUS PRESSURES OF CARBON MONOXIDE CARBON DIOXIDE MIXTURE

to absorb any great excess of carbon dioxide. I is the pressure furnace. It is made from a piece of ten inch steam main, eighteen inches long, threaded at both ends and fitted with companion flanges. The ends are closed by bolting copper plates between the flanges at each end. A rubber gasket between the plate and the inside flange serves to make the chamber hold pressure up to 100 pounds. In the center of this chamber is placed a twelve inch heating element J. This is held in place by a silocel packing and

heat insulator. The gas mixture is led in through the rear plate directly to the end of this element. The end of the element is closed with transite board washers. The element is heated by 110 volt alternating current and the temperature controlled by placing rheostats in the circuit. K is a nickel receptacle with an iron lining on its upper surface, the sample is placed in this and packed with finely divided carbon, graphite or wood charcoal, leaving only the end next to the observation tube P exposed. The temperature is recorded by means of an optical pyrometer focused through P on the sample. The stop cock L is left partially open during the anneal and the gas mixture burned at this point. At frequent intervals samples of the gas are withdrawn here, collected over mercury, and analyzed for carbon monoxide and carbon dioxide by use of an Orsat gas analysis apparatus.

The sample to be annealed, usually about two and one-half inches long and seven-eighths inch in diameter, is placed in K and packed with carbon as described. The receptacle is placed approximately in the center of the heating element and the front plate and flange bolted on. Transite board washers with a one-fourth inch hole may be used to fill the end of the heating element. They prevent considerable radiation and are specially necessary in annealing long samples.

The tube G is filled about two-thirds full of the potassium hydroxide solution and is assembled in the line. This and the carbon chamber should be refilled after each anneal but the drying tubes need not be filled more than once in three or four runs.

After the muffle furnace has reached 927 degrees Cent. the control valve C is opened slightly and the carbon dioxide is allowed to pass slowly into the apparatus. The stock cock L is left open and as soon as the gas will burn here a sample is collected and analyzed. When the proper mixture is obtained, the stop cock is nearly closed and the gas pressure is slowly built up. To reach a total pressure of five atmospheres and a composition of about 95 per cent carbon monoxide, it requires about thirty minutes to build up the pressure.

As soon as the proper pressure has been reached the current is turned on in the pressure furnace without any resistance in the

circuit. It requires about fifteen minutes for the sample to come to dull red heat at this rate and about twenty minutes longer to reach 927 degrees Cent. By adjustment of the rheostats this temperature can be accurately maintained for any given length of time. On cooling it requires twenty-five to thirty minutes to cool from 927 degrees Cent. down to dull red heat again.

A consideration of the mechanism by which this gas mixture acts will show definitely that a gas mixture richer in carbon monoxide than that corresponding to the equilibrium value for carbon will introduce carbon into austenite saturated with carbon from carbon. It also indicates that a still higher value of carbon monoxide would convert iron into free iron carbide and that a carbon monoxide content less than that corresponding to equilibrium with carbon would oxidize carbon from a sample saturated with carbon either from cementite or carbon.

The first portion of the work was carried out to determine the length of time necessary to initiate graphitization at 927 degrees Cent. under a pressure of five atmospheres per square inch. Earlier work done in this laboratory had shown that from twenty to thirty minutes were required to start graphitization sufficiently at this temperature and at a pressure of one atmosphere so that definite temper carbon spots could be detected.

Accordingly, treatments were made of pieces of white iron test bars under a pressure of five atmospheres and in a carbon pack at one atmposhere, both at 927 degrees Cent. for a thirty minute anneal at the high temperature.

The time necessary to bring the temperature of the samples from a dull red heat up to 927 degrees Cent. was about fifteen minutes. About thirty minutes were required to cool the samples through this same temperature interval. These times were duplicated to within five minutes in the treatment of the two samples.

It will be readily seen that the composition of the gas mixture can be regulated by the temperature at which the carbon tube E was maintained.

At a temperature of 927 degrees Cent. a mixture of 85 to 95 per cent carbon monoxide was used. The higher value was used

at the beginning of the run and is very near the equilibrium value for the gases in contact with carbon at this temperature and at a total pressure of five atmospheres.

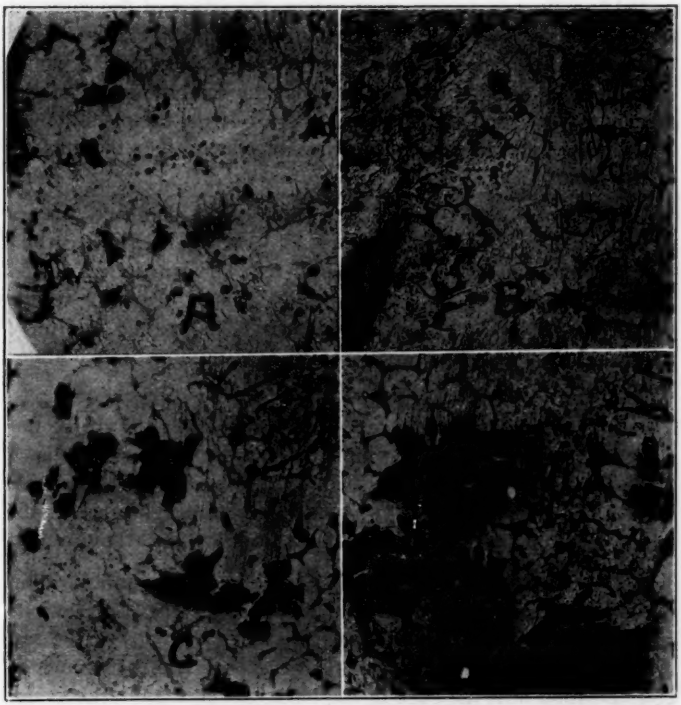

FIG. 4—A, EDGE; B, CENTER—½ HR. AT 1 ATMOSPHERE, 927° C.—SODIUM PICRATE ETCHED X 88

C, EDGE; D, CENTER—½ HR. AT 5 ATMOSPHERES, 927° C.—75 LB. PRESSURE, 97 PER CENT CO, 3 PER CENT CO_2—SODIUM PICRATE ETCHED X 88

In all the samples treated there was some decarbonization near the surface which shows that the gas mixtures employed were slightly richer in carbon dioxide than is required to establish equilibrium with carbon.

Since the gases come to equilibrium with the dissolved and free carbon quickly at the high temperature in penetrating the surface layers, a slight variation of the composition of the gas mixture from those representing equilibrium would not be expected to influence, to any great extent, the action of the gases on the interior of the piece. This has proved to be the case. Even when the gas mixture was richer in carbon monoxide than would correspond to equilibrium with carbon, the catalytic effect of the gases was very pronounced on the interior of the sample although a distinctly hypereutectoid case was introduced into the surface of the piece.

In Fig. 4 A and B is shown at eighty-eight diameters the results of a thirty minute anneal at 927 degrees Cent. in a carbon pack and at a pressure of one atmosphere. The sample was etched with sodium picrate. In C and D of the same figure is the results of a treatment of a piece of the same test bar, treated for thirty minutes, but at a total pressure of the gas mixure of five atmospheres.

In Fig. 7 A and B at twenty-two diameters is shown the unetched surface of the same sample as that in A and B of Fig. 4 while C and D of Fig. 7 is a similar photograph of the sample shown in C and D of Fig. 4. A and C in each figure are of the edge of the pieces while B and D are of fields near the center.

The very marked speed-up in the initiation of graphitization in the sample treated under pressure is evident. The fact that initiation of graphitization is earlier in the outer portions of the test piece is also evident. That this difference in the beginning of graphitization near the edge of the piece and on the interior is not caused by the application of the gases under pressure may be seen by comparing Fig. 8 A and B with Fig. 7 C and D. Fig. 8 A and B shows the result of a one hour treatment in a carbon pack at a pressure of one atmosphere. It shows a variation in number and size of carbon spots near the surface and on the interior which is very similar indeed to that shown in Fig. 7 C and D.

The conclusion, of course, is that the same changes take place at a much earlier period in the presence of a mixture of carbon monoxide and carbon dioxide when applied under a pressure of

five atmospheres than is the case when a total pressure of one atmosphere is used.

Time Necessary to Absorb Massive Cementite

An attempt was next made to determine the time necessary at 927 degrees to absorb essentially all of the free iron carbide at pressures of five atmospheres and one atmosphere respectively.

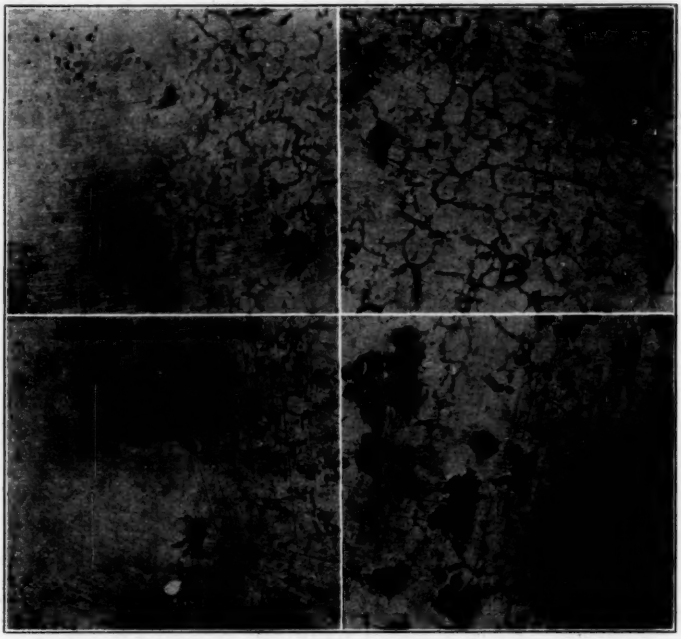

FIG. 5—A, EDGE; B, CENTER—3 HRS. AT 1 ATMOSPHERE, 927° C.—SODIUM PICRATE ETCHED X 88

C, EDGE; D, CENTER—4 HRS. AT 1 ATMOSPHERE, 927° C.—SODIUM PICRATE ETCHED X 88

Samples were treated for varying intervals at five atmospheres and at one atmosphere until only grain boundary cementite remained.

At five atmospheres the time at the high temperature of 927 degrees Cent. was increased by half hour increments until an anneal of two and one-half hours was made. At one atmosphere the same increment of time was used but no treatment was made for a shorter time than one hour at the high temperature.

In all cases, at both pressures, an attempt was made to duplicate the time of twenty minutes to heat from the critical temperature to 927 degrees Cent. and also to cool the sample from 927 degrees Cent. to the critical in thirty minutes. There was never a variation of more than five minutes in either of these times. Thus and differences in time at the high temperature should indicate the catalytic effect of the gas mixture applied under the two different pressures.

In Fig. 5 A and B is the result of a three hour treatment at 927 degrees Cent., while C and D. of this figure show the structure produced by a four hour treatment. Both anneals were made at a pressure of one atmosphere. There are some fragments of massive cementite in A and much less in B. Smaller quantities are present in C than in A while in D practically all massive cementite has been destroyed.

Fig. 6 A and B show the structure resulting from a two hour treatment at 927 degrees Cent. and a pressure of five atmospheres. C and D are of a two and one-half hour treatment under the same conditions.

On the interior of the piece, graphitization has proceeded nearly as far in two hours at five atmospheres (Fig. 6 B) as it did in four hours at one atmosphere (Fig. 5 D).

There is present somewhat more grain boundary comentite near the surface of the piece (Fig. 6 A) than is the case where one atmosphere was used for three hours (Fig. 5 A). A comparison of Figs. 6 C and D with 5 C and D shows that no doubt a treatment for two and one-half hours at five atmospheres has carried graphitization as far as a treatment for four hours at one

atmosphere. Thus there is a reduction of from thirty-seven to fifty per cent of the time necessary for the absorption of the massive cementite produced by the application of a mixture of carbon monoxide and carbon dioxide at a pressure of five atmospheres instead of one.

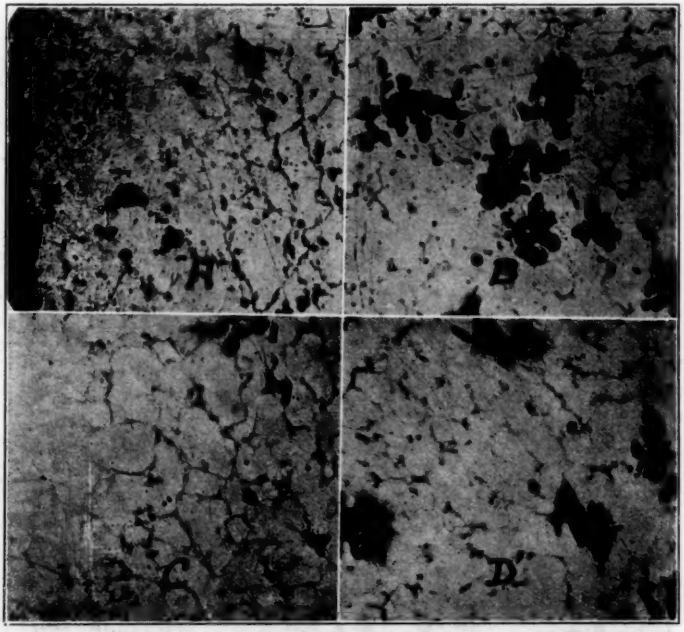

FIG. 6—A, EDGE; B, CENTER—2 HRS. AT 5 ATMOSPHERES, 927° C.—75 LB. PRESSURE, 89 PER CENT CO, 11 PER CENT CO_2 — SODIUM PICRATE ETCHED X 88

C, EDGE; D, CENTER—2½ HRS. AT 5 ATMOSPHERES, 927° C.—75 LB. PRESSURE, 90 PER CENT CO, 10 PER CENT CO_2

There is a peculiar fact which should be noted. Graphitization is initiated earlier in the surface layers than in the interior of the piece at both pressures, while it proceeds more slowly in this portion during later periods of the anneal. This is shown by the greater quantities of grain boundary and massive cementite of Fig. 5 which is the result of an anneal at one atmosphere and

also in Fig. 6 representing the structure produced by annealing at five atmospheres.

A discussion of this fact will be taken up in a publication on "Picture-Frame Malleable" which will appear soon.

Fig. 9 A and B and C and D show a marked difference in the size and number of temper carbon spots in the surface and interior

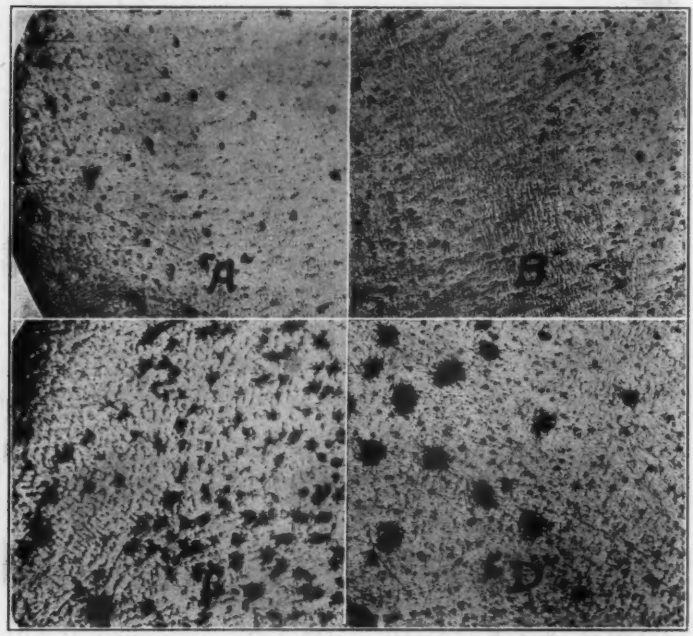

FIG. 7—A, EDGE; B, CENTER—SAME AS FIG. 4 A AND B—UNETCHED X 21

C, EDGE; D, CENTER—SAME AS FIG. 4 C AND D—UNETCHED X 21

of bars given treatments at five atmospheres. That this is not due to the increased pressure of the gas mixture is shown by Fig. 8 C and D, which structure was produced by a treatment at one atmosphere.

Action of the Gas Mixture While Cooling the Sample from the High Temperature

Although the application of carbon monoxide and carbon dioxide mixtures at a pressure of five atmospheres speeds up the rate of absorption of the free iron carbide nearly one hundred per

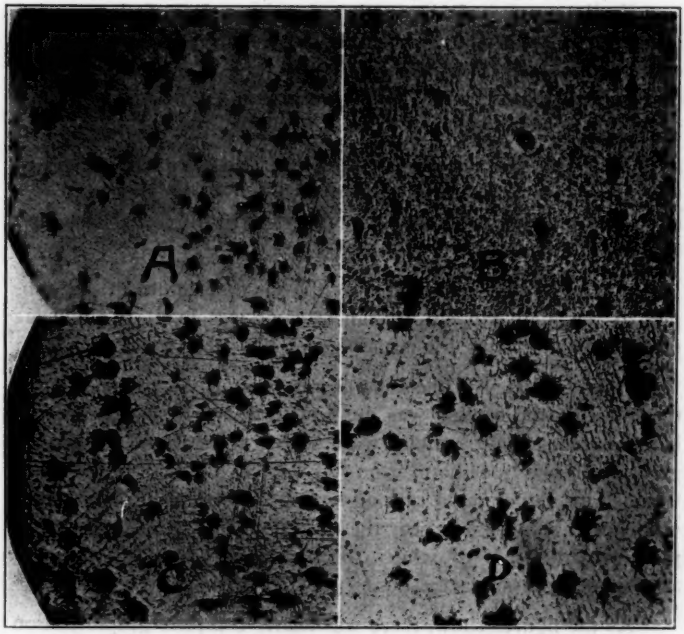

FIG. 8—A, EDGE; B, CENTER—1 HOUR AT 1 ATMOSPHERE, 937° C.—UNETCHED X 21

C, EDGE; D, CENTER—2½ HRS. AT 1 ATMOSPHERE, 937° C.—UNETCHED X 21

cent at 927 degrees Cent., quite the reverse effect results when cooling the sample through the critical range. In fact the amount of graphitization brought about during the cooling from the high temperature through the critical temperature is very much less when the gas mixture is applied at five atmospheres than is the

case when one atmosphere is used. This can readily be seen by comparing Figs. 10 and 11.

In these treatments, an attempt was made to complete the absorption of free iron carbide annealed under five atmospheres and also in the one annealed at one atmosphere while at the high temperature.

Earlier work had shown that the absorption of the massive cementite was usually complete at the end of four hours at 927 degrees Cent. where a pressure of one atmosphere was used and that only two and one-half hours were required when five atmospheres were employed.

Thus the sample treated under one atmosphere was held at the high temperature for four hours while the one treated at five atmospheres was maintained at this temperature for two and one-half hours.

Having established essentially the same structure in the samples at the high temperature, an attempt was made to duplicate the treatments during the remainder of the process.

As is indicated in the legends for Figs. 10 and 11, the treatment during the cooling was duplicated as nearly as possible for both samples. Both samples were cooled at a rate of twenty degrees Fahrenheit per hour from 771 degrees Cent. to 677 degrees Cent. This rather rapid rate of cooling through the critical range was chosen because it is near the critical cooling rate for the complete graphitization of white iron or normal composition under atmospheric pressure.

As the figures show, there was nearly complete graphitization on the interior of the sample treated at one atmosphere although there remain fragments of massive iron carbide in certain portions near the center. There is marked picture frame formation as indicated by the pearlitic rim near the surface of the sample.

In the piece treated at five atmospheres there is much less massive iron carbide remaining. In marked contrast with the results of the one atmosphere treatment, it shows a nearly pearlitic matrix. Thus at rates of cooling in the vicinity of twenty degrees Fahrenheit per hour the gas mixture has a marked retarding influ-

ence on graphitization while cooling the sample through the critical range. Rates of cooling through the critical range varying from 3½ to 400 degrees Cent. per hour have been used. Accompanying this wide variation in cooling rates, the matrix varies from about eighty to one hundred per cent pearlite. In other words, this gas mixture at five atmospheric pressure almost completely

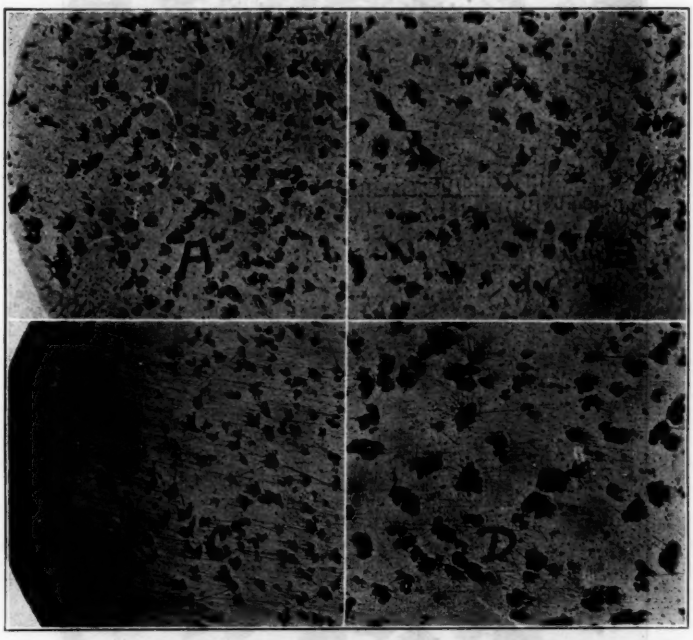

FIG. 9—A, EDGE; B, CENTER—SAME AS FIG. 6 A AND B—UNETCHED X 21
C, EDGE; D, CENTER—SAME AS FIG 6 C AND D—UNETCHED X 21

inhibits graphitization in the critical range for cooling rates varied over wide limits.

This behavior offers an almost automatic method of obtaining castings of maximum strength with from five to eight per cent elongation. The explanation of this is not difficult to find, and as will be seen it suggests some very interesting possibilities.

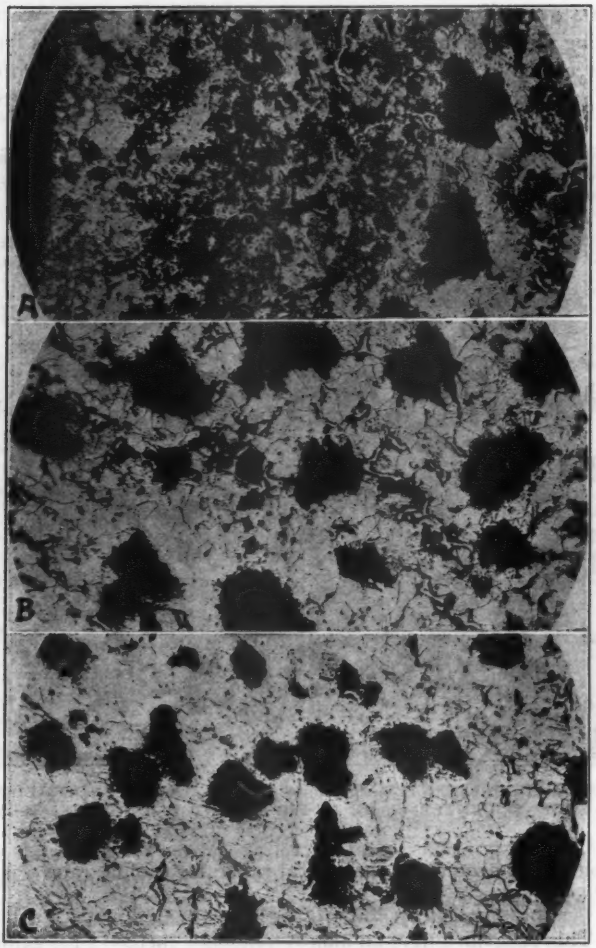

FIG. 10—A, EDGE; B AND C, NEAR CENTER—4 HRS. IN CARBON PACK AT ONE ATMOSPHERE, 927° C.—COOLED TO 771° C. IN 1 HR. AND 40 MIN.—COOLED TO 677° C. IN 8½ HRS.—ETCHED IN NITRIC ACID X 90

Rhead and Wheeler[3] concluded that it was impossible to obtain equilibrium for the reaction

$$(1) \quad 2\,CO \rightleftharpoons C + CO_2$$

at temperatures much below 800 degrees Cent. because the reaction velocities become too slow to make feasible an experimental determination of the equilibrium values for the gases. Their

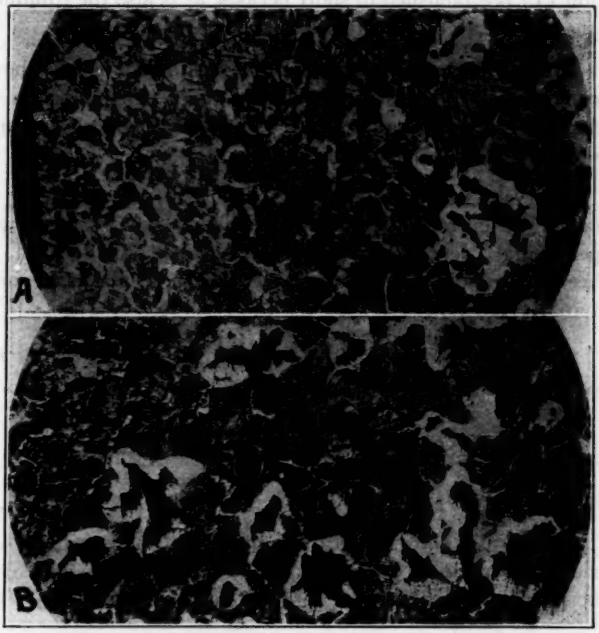

FIG. 11—A, EDGE; B, CENTER—2½ HRS. AT 5 ATMOSPHERES, 927° C., 90 PER CENT CO, 10 PER CENT CO_2—COOLED TO 771° C. IN 1 HR. AND 50 MIN.—60 PER CENT CO, 40 PER CENT CO_2—COOLED TO 677° C. IN 8½ HRS.—30 PER CENT CO, 70 PER ENT CO_2—ETCHED IN NITRIC ACID X 90

work shows that this reaction is extremely slow at 700 degrees Cent. A careful consideration of their data at 800 degrees Cent. seems to indicate that they did not get complete equilibrium for

[3]Jnl. Chem. Soc., Vol. 99, p. 1140 (1911).

the reaction (1). Work done in this laboratory shows that in the reaction

$$(2) \quad 3\ Fe\ (alpha) + 2\ CO \rightleftharpoons Fe_3C + CO_2$$

equilibrium is established at 650 degrees Cent. in thirty-two hours and at 700 degrees Cent. in somewhat less time.

At temperatures above 800 degrees Cent., equilibrium for reaction (1) is established in short periods, as is also the equilibrium of the gases with dissolved carbon and free iron carbide.

In Fig. 12 is shown the carbon monoxide content of the carbon monoxide and carbon dioxide mixtures in equilibrium with carbon over the temperature range 650 to 1000 degrees Cent. and at pressures of one and five atmospheres.

The values for temperatures below 800 degrees Cent. were obtained by extrapolation from the higher temperatures where experimental determinations were obtained by Rhead and Wheeler. In this extrapolation the change in the heat content ΔH of the reaction

$$2\ CO \rightleftharpoons C + CO_2$$

was taken as —41950 calories and the equation

$$2.303 \log \frac{K_2}{K_1} = \frac{\Delta H}{R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$

was used.

Fig. 12 also shows the carbon monoxide content of the equilibrium gas mixtures for reaction (2) and at a pressure of one atmosphere.

If it is assumed that the gas mixture used in this work is the effective agent in the graphitizing process it follows that: In order for graphitization to take place it is necessary first to have reaction (2) approach a value near its equilibrium value. Second, it is then necessary to have reaction (1) proceed from left to right until carbon has been deposited and the carbon dioxide content of the gas mixture is correspondingly increased. These two reactions are then repeated in turn, the carbon monoxide content of the gases being increased in the vicinity of cementite or solid solution

of carbon from cementite, followed by deposition of carbon and formation of carbon dioxide in the vicinity of the temper carbon.

If for any reason reaction (1) should become extremely slow while reaction (2) would continue to have comparatively rapid rates of approach, to equilibrium, the result would be that such cooling rates, as were used in this work, would result in the gas mixture being as rich or possibly even richer in carbon monoxide than would correspond to equilibrium for reaction (2). This would have a tendency to stop the action of the gases in the catalysis of graphitization or possibly even to increase the combined carbon content of the metal.

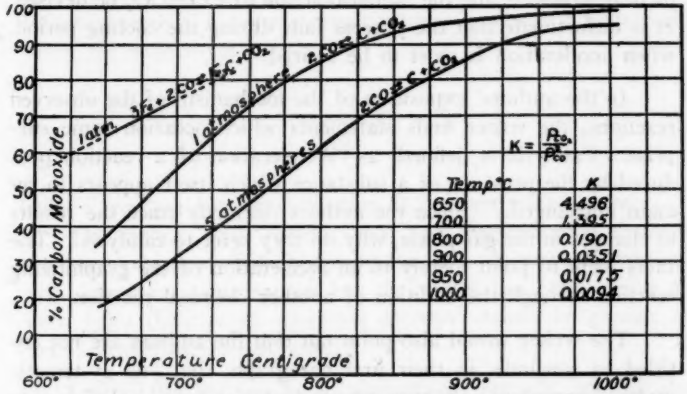

FIG. 12—COMPOSITIONS OF GASES IN EQUILIBRIUM WITH CARBON AND IN EQUILIBRIUM WITH ALPHA IRON AND IRON-CARBIDE

Conclusion

(1) At temperatures of 927 degrees Cent. carbon monoxide carbon dioxide mixtures increase the rate of absorption of free iron carbide nearly 100 per cent.

(2) During cooling at rates varying from 3½ degrees Cent. per hour to 400 degrees Cent. per hour, it inhibits almost completely graphitization in the critical range.

(3) An explanation of these actions is given.

(4) The action of the gas mixture offers a very convenient method of obtaining a pearlitic matrix in the partial graphitization of white iron.

WRITTEN DISCUSSION

H. A. SCHWARTZ,* Cleveland, O.

The authors have confirmed the observation of Honda and Murakami, that the conversion of CO into CO_2 and vice versa may be a factor in graphitization. The Japanese introduced CO forming ingredients into iron chemically, while the present authors do so mechanically and secure similar results.

The observation may have commercial importance if a suitable container, capable of economic life under the combined action of heat, pressure, and the chemical action of CO—CO_2 be devised. It is unfortunate that the process fails during the cooling period, when acceleration is most to be sesired.

In the authors' exposition of the mechanism of the observed reactions, the writer finds statements which occasion some surprise. Catalysis is defined[1] as "Acceleration of a reaction produced by the presence of a substance which itself appears to remain unchanged." Since the authors distinctly trace the results to changes in the gas phase, why do they refer to catalysis? The facts seem to point merely to an acceleration of the graphitizing reaction through the addition of another chemical reaction.

The writer would also point out that the authors are not entitled to conclude, in their first paragraph, that "no systematic study of annealing oven atmospheres had ever been made," merely because they have not found them described in the literature.

It is unfortunate that the authors trace the progress of graphitization entirely upon metallographic evidence. Microscopy is a very sensitive tool for determining the beginning and end of the reaction, but not well suited to the intermediate stages. Chemical data regarding graphitization would have formed a welcome corroboration.

On page 592 the authors state that reaction (2) establishes equilibrium at 650 degrees Cent. in about 32 hours. Is not this time altogether dependent upon the relative amounts of solid and

*Director of Research, National Malleable and Steel Casting Co.
[1]Webster's New International Dictionary.

gas phase, on the state of subdivision of the solid phase, and the rate of circulation of the gas?

At the foot of page 587 the authors apparently promise an explanation of why an increase in pressure should inhibit graphitization during the cooling range, while accelerating it at high temperatures. The only subsequent reference to the effect of pressure on the reaction is in connection with Fig. 12, and its explanation, and even there the effect of pressure on the locus of the equilibrium curve for the reaction $3\,Fe + 2CO = Fe_3C + CO_2$ is ignored. As a matter of fact, the relation between CO concentration (x) and pressure (P) for equilibrium conditions follows precisely the same quantitative relations for both reactions, the expression

$$\frac{x^2}{1-x} P$$

being a constant for either reaction at constant temperature.

The authors very clearly show why graphitization through the intervention of $CO\text{-}CO_2$, mixtures may decrease in rapidity with decreasing temperature, but the writer has been unable to learn from their paper why this decrease should be greater at higher pressures than at lower.

Lastly, the authors have, throughout, entirely ignored the conclusions of Schenck and his coworkers[2]. These investigators who have specialized in the field of $CO\text{-}CO_2$ equilibria for many years, have set up an equilibrium diagram according to which the reactions postulated by Hayes and Scott and by Honda and Murakami can not proceed in the direction assumed at temperatures above 700°C.

This general conclusion has been confirmed by the experiments of Giolliti[3] and accepted by Matsubara[4]. Further, it explains equilibria observed with .90 carbon steel in the writer's

[2]Schenk and Dean, "Physical Chemistry of Metals," Chaps. IV and V. Jihn Wiley and Sons, New York, 1919; also Stahl and Eisen, May, 1924, p. 524.

[3]Giolliti, Cementation of Iron and Steel, Chap. II. McGraw-Hill, 1915.

[4]Chemical Equilibrium Between Iron, Carbon and Oxygen, Trans. A. S. M. E., LXVIII, p. 3, 1922.

laboratory, and the fact, observed here, that wash metal will gain carbon to over 5 per cent when heated in a sealed tube originally containing air and carbon powder.

While the results of Schenck, et al. are worthy of the most serious consideration both because of their long experience, and because their conclusions explain satisfactorily the work of others, they are of course, not sacrosanct, and may be attacked by anyone in the light of new and sufficient evidence.

If the present authors are prepared to take issue with the most recent conclusions of Schenck, then a dissertation covering specifically the necessary corrections, to that experimentor's equilibrium diagrams, and offering proof, in extenso, supporting their position, would have formed a most significant contribution to the literature of graphitization, for which it is regrettable that space was not found in the present paper.

If, on the other hand, they have merely observed a single fact, inconsistent with the conclusions of their predecessors in the field, then it is to be regretted that they did not seek a cause explaining the discrepancy rather than set up as an explanation of their observations, a series of reactions at variance with previously accepted and well supported opinions. Thus, the reader is left in grave doubt as to what weight he should give to the physical chemistry of the paper. It is irreconcilable with our previous conceptions, without furnishing any new explanation for facts with which those conceptions were in harmony.

The purpose of the present writer is not to solve this riddle. He has had occasion to study the equilibria in the system Fe-C-O only intermittently during the past ten or twelve years, and those involving Fe_3C have been the subject of reflection and experiment for only about five years, involving perhaps, six months of intensive experimentation. So far, he has found no reason to question the general accuracy of the Schenck's conception, except in connection with the work of Honda, who advanced the same views now defended in the paper under discussion.

He has no desire to become the protagonist of any specific theory as to the part played by gases in the graphitizing process,

but would advance the suggestion that one cause of the discrepancy may be that graphitization, in general, occurs in alloys so impure that it may be necessary to treat them as ternary systems in which case, reasoning applicable to a binary solid phase could no longer be applied.

It is also possible that carbon migrates more readily from a solid solution rich in carbon to one poorer in carbon in the form of CO than as C, Fe_3C, or other solid forms. The presence of a gas phase may then accelerate graphitization by its influence on migratory rates without the necessity of postulating the separation of free carbon from CO. The process might then perhaps be properly considered catalytic.

Pending a resolution of this difficulty, it will perhaps be safest to concentrate our attention upon the observational facts of the present paper rather than to place too much confidence in the explanatory theory.

AUTHOR'S REPLY SUBMITTED BY LETTER BY A. HAYES

When the authors prepared this paper the fact was recognized that it would be read by many industrial men who are not specialized in the field of physical chemistry. With this in mind the context was written so as to present complete details of the experimental work and its results. A complete proof of the latter would occupy many pages of additional material, especially if it were to include the academic presentation of such subjects as "The Intermediate Compound Theory" of catalysis and a treatise of "The Principles of Heterogeneous Equilibria." As will be noted by the casual reader suggested methods of calculation and references to the literature are given.

By such an arrangement it was hoped that the industrial man would get accurately and clearly the important points in the explanation and that anyone interested in research work in this field could readily supply the details of the proof.

Before taking up the main defense of the paper, two points which have been raised in the discussion should be taken up.

The first of these is in regard to our statements to the effect that there was an almost complete lack of available knowledge of the effects of annealing oven atmospheres on the properties of the product and upon the annealing process.

I wish to say that this statement was made after conferences with three very successful metallurgists in the malleable industry and also after failing to find any work along this line in the literature. These three metallurgists are connected with three malleable concerns who are members of the American Malleable Castings Association.

The second point is in regard to the use of the metallographic method in tracing the progress of graphitization. As Mr. Schwartz has stated, the metallographic method is especially adapted to the determination of the initiation and completion of graphitization. The writer wishes to state that it is also a very satisfactory method of detecting the complete absorption of massive iron carbide.

Hayes and Flanders have had occasion[1] to test the reliability of the use of the microscopic method for the last mentioned purpose and have found it to be very satisfactory. In no case in the present experimental work were conclusions drawn from the results of a single treatment, or from the appearance of a few microscopic fields. All experiments were repeated a number of times, and many fields were examined at sufficient depths to eliminate surface influences where knowledge of internal structures was desired. As is shown in the figures, examinations were made of both etched and unetched fields. Further, the figures are photographs of fields carefully selected as being representative. Under such conditions, the very marked differences in structures resulting from different treatments should be entirely trustworthy.

The writer regrets very much that the authors attempt to shorten the article and avoid what seemed to them to be an unnecessary presentation of academic material has caused Mr. Schwartz to fail to understand the contents of the paper.

It seems especially regretable that an attempt has been made to attribute the intentional omission of considerable academic material to a lack of knowledge, on the part of the authors, of what is in a number of cases very elementary principles of physical chemistry. The authors did not consider it necessary to present a treatise on the modern theories of catalysis in order to justify the title of the paper. Yet, as was pointed out in the oral reply at the convention, the case under consideration is an especially good illustration of one very common type of catalysis.

A second instance of an attempt by Mr. Schwartz to discredit the authors in his statements in regard to the time necessary for the gas mixture to reach equilbrium, with the solid phases present as mentioned on page 592 of this volume.

The reference to the work of Rhead and Wheeler is given in order that anyone not familiar with their latest and most important work can go to the original article and acquaint themselves with it. Had the reader in

[1]A. F. A. Trans. Vol. 33, pp. 634-637.

this case been inclined to do this, before launching an attack upon the present work, he would have found that Rhead and Wheeler were unable to arrange a set of conditions as regards surface of solid carbon and contact of gas phase with solid carbon so that equibrium could be attained at temperatures lower than 800 degrees cent. between solid carbon, carbon monoxide, and carbon dioxide. Had he been inclined to study further the work done in this field, he would have found that all attempts to use metallic or other catalysts in reaching a condition of equilbrium of these gases with carbon have failed because a different equibrium was reached with each "would-be" catalyst. The fact is that this equilibrium is not established at temperatures less than about 800 degrees cent. under any conditions tried up to the present time.

Thus the statements in the present paper hold under almost any conditions of surface of solid phase and rate of circulation of gasses though it is true that the conditions that existed in the experiments of Rhead and Wheeler with carbon are very similar to those employed by Dr. Harold L. Maxwell in obtaining equilibrium in thirty-two hours for reaction (2) of page 592 of this volume.

A third instance of this kind is shown in the failure of Mr. Schwartz to understand the explanation of the action of the gases at the high temperature and while cooling through the lower critical range. On page 576 the expression is given with an explanation of its significance where the

$$\frac{1-X}{X_2}=K_1$$

total pressure of the gas mixture is one atmosphere. On page 575 is given an exactly similar expression of the equlibrium constant for reaction (2) of page 574 where the pressure is also one atmosphere.

In view of this fact, the authors are greatly puzzled as to how the reader would reach the conclusion that they had failed to appreciate the fact that the effect of pressure upon the position of the temperature curve for equilibrium (2) of page 592 would be similar to its effect upon the temperature curve for equilibrium (1) of page 591 (which is the same as equilibrium (2) of page 574 as shown in Fig. 12.)

If Mr. Schwartz had gone a step further than that of noting that the temperature curves for equilibrium (1) of page 591 and (2) of page 592 are both shifted downward by an increase in pressure and had made the calculation suggested on page 576 of the paper, but for a pressure at one atmosphere and again at five atmospheres, he would have found that the pressure gradient at five atmospheres for carbon monoxide is greater from the metastable phase to the stable phase than it is at one atmosphere. The pressure gradient for carbon dioxide in the opposite direction is also higher at five atmospheres.

Having noted the effects of pressure upon these pressure gradients, it is only necessary to make the very plausible assumption that rates of diffusion of these gases increase as the pressure gradient grows larger, in order to understand the acceleration of graphitization at the high temperature.

The authors might have stated conclusion (2) on page 593 somewhat as follows: A carbon monoxide and carbon dioxide mixture is not the active agent for graphitization at any pressure, while the iron is cooling through the lower critical range.

Since graphitization does take place in the critical range when the pressure of carbon monoxide carbon dioxide mixtures is sufficiently low, the conclusion is reached that there is some other process at work by which graphitization takes place, we might say, in spite of the presence of the carbon monoxide carbon dioxide mixture. The writer was greatly interested by the reports of E. Touceda and H. A. Schwartz in the discussion of a paper[2] at the Milwaukee convention of the A. F. A. in 1924. In these reports they stated that when white iron was heated to temperatures in the vicinity of the lower critical range, while in a very high vacuum, essentially all of the carbon, both combined and free, disappeared from the piece. After some discussion the conclusion was reached by them that the carbon distilled out of the metal in the form of vapor. It might thus seem possible that carbon vapor is the positive graphitizing agent in the critical range. The authors do not feel that they have established what the active agent is, but they do claim to have established the fact that carbon monoxide carbon dioxide mixtures are not the active agent while cooling in the critical range.

While the iron is cooling through the lower critical range the extremely slow approach to equilibrium for reaction (1) of page 591 makes certain that the gases will be too rich in carbon monoxide to be in equilibrium with carbon. In fact, the falling temperature may cause the gases to be richer in carbon monoxide than corresponds even to equilibrium for reaction (2) of page 592. Any gas mixture richer in carbon monoxide than a composition representing that of equilibrium with carbon must be carbonizing to iron saturated with carbon from carbon. Should the mixture contain more carbon monoxide than represents equilibrium for reaction (2) of page 592 free iron carbide should be formed.

The concept which the authors have of this inhibiting action of the gas mixture in the critical range is as follows: There is some active agent, for example, carbon vapor distillation, by which carbon moves from regions where its vapor pressure is higher, to those where it is lower, i. e. from a metastable form over to a stable form. The carbon monoxide carbon dioxide mixture at all pressures retards the action of this positive graphitizing

[2]Trans. A. F. A. vol. 32, part 1, pp. 634-636, 1925.

agent because during the cooling process it has remained too rich in carbon monoxide and thus is a carbonizing agent instead of being a graphitizing agent. Due to the higher pressure gradients at higher total pressures, it counteracts the positive graphitizing agent more strongly than it does at lower total pressures.

Now the writer wishes to go into a detailed defense of the crime he apparently has committed in disregarding the conclusions which Schenck and Matsubara have reached from studies of equilibria with various solid phases and with the gas mixture of carbon monoxide and carbon dioxide. The system studied by these workers was the pure three component system, iron, carbon, and oxygen. The studies of Schenck were made below the critical range while Matsubara investigated the behavior of this system at temperatures where solid solutions are formed.

Before proceeding to a discussion of the behavior of white iron compositions either in the absence of or presence of appreciable quantities of this gas phase, a careful analysis of Schenck's conclusions and of the conclusions of the authors as shown in Fig. 12 of the paper should be made. The data for equilibrium for reaction (2) of page 592 is taken from the results obtained by Dr. Harold L. Maxwell in work which he has done on the pure three component system mentioned above. His studies were made over the temperature interval 650 degrees cent. to 700 degrees cent. and at a total pressure of one atmosphere.

In Fig. 1 (page 604) of the present discussion is reproduced Schenck's latest publication[3] on this subject.

Before going to a discussion of these figures, the very close relation between the following chemical reactions should be appreciated. These reactions may be considered to accurately represent two possible mechanisms for graphitization of pure iron carbon alloys below the critical range.

(1) $2CO = C + CO_2$
(2) $3\ Fe\ (alpha) + 2CO = Fe_3C + CO_2$
(3) $Fe_3C = 3\ Fe(alpha) + C$

The fact was pointed out by Schenck that the net result of reactions (1) and (2) i. e., reaction one proceeding toward the right and reaction (2) toward the left is the equivalent of reaction (3) proceeding toward the right.

Now if we let ΔF_1, ΔF_2 and ΔF_3 represent respectively the change in the free energy content (the change in the value of the Gibbs Zeta function, for a more complete discussion of which see Thermodynamics by Lewis and Randall, McGraw-Hill) accompanying each of these reactions when proceeding from left to right then the second law of thermodynamics

[3]Stahl und Eisen, May, 1925, p. 524.

demands that $\Delta F_1 - \Delta F_2 = \Delta F_3$. If this were not the case, a cyclical process involving reaction (3) proceeding in one direction and of reactions (1) and (2) so as to carry out the equivalent of reaction (3) in the opposite direction, could be carried out in such a manner as to accumulate an indefinite quantity of available energy. Thus to be more specific, assume that reaction (3) represents a spontaneous process when proceeding from left to right and that during the breakdown of one formula weight of the carbide, a quantity of available energy ΔF_3 is stored up and that this quantity of energy is greater than $\Delta F_1 - \Delta F_2$ which latter quantity represents the available energy stored up when the same change is carried out by means of reactions (1) and (2).

Under such a set of conditions, it would be possible to use a portion of the energy ΔF_3 to produce a formula weight of the carbide Fe_3C from carbon and alpha iron by means of the two reactions (1) and (2) carried out in the reverse direction. When this is accomplished, all of the various substances are in the original condition and as a net result we have gained a quantity of available energy represented by the quantity $\Delta F_3 - (\Delta F_1 - \Delta F_2)$. The conclusion thus reached is that $\Delta F_3 = (\Delta F_1 - \Delta F_2)$.

The mass law equilibrium constants for reactions (1) and (2) may be represented by the following expressions

$$K_1 = \frac{P_1\text{—}co_2}{P_1^2\text{—}co} \text{ and } K_2 \frac{P_2\text{—}co_2}{P_2^2\text{—}co_2}$$

where P represents the partial pressures of the carbon monoxide and carbon dioxide at equilibrium with the solid phases for reactions (1) and (2) respectively.

Now $\Delta F_1 = -RT\ln K_1$ and $\Delta F_2 = -RT\ln K_2$ where the reactants are brought into the reaction at unit pressure and where the products of the reaction are removed at unit pressure, (See Lewis and Randall, Thermodynamics, McGraw-Hill) and where R is the molal gas constant and T is the absolute temperature.

From these relations it follows that

$$\Delta F_3 = \Delta F_1 - \Delta F_2 = RT(\ln K_2 - \ln K_1).$$

If reaction (3) is a spontaneous process ΔF_3 must be negative, i. e., the free energy content of Fe_3C must be greater than that of 3Fe (alpha) + C. This in turn requires that

$$K_2 < K_1 \text{ or that } \frac{P_2\text{—}co_2}{P_2^2\text{—}co} < \frac{P_1\text{—}co_2}{P_1^2\text{—}co}$$

if the total pressure is constant at one atmosphere, this requires that

$$P_2\text{—}co_2 < P_1\text{—}co_2 \text{ and that } P_2\text{—}co > P_1\text{—}co$$

An examination of our Fig. 12 of our paper and of Fig. 1 of this reply taken from Schenck shows that they are both in agreement in indicating that Fe_3C is metastable within the temperature range 650 to 700 degrees cent. They are not in entire agreement in that the slope of the temperature, equilibrium curves of reaction (2) as represented in our Fig. 12 of the paper and as shown by Schenck are distinctly different. As to which slope is the correct one, I will only state that the slope obtained in this laboratory gives a value for the heat of formation of Fe_3C that agrees fairly well with the calormetric value of Ruff and Gestern,[4] which value has been generally accepted, while the value calculated from Schenck's results is in wide disagreement with it. Furthermore Schenck's value agrees well with the calormetric work of Campbell,[5] whose work was based upon the assumption of the two reactions

$$3\,Fe + 6\,CuCl_2 = 3\,FeCl_2 + 6CuCl \text{ and}$$
$$Fe_3C + 6\,CuCl_2 = 3\,FeCl_2 + 6\,CuCl + C$$

according to which the heat of formation of Fe_3C is the difference between the heat effects accompanying these two reactions. The error in Campbell's work is due to the fact that he assumed that the carbon was left as the element carbon, while the fact is that since he found it necessary to add considerable quantities of hydrochloric acid in order to get the second reaction to go, large portions of the combined carbon were evolved as hydrocarbons.

Since Schenck's result, for the heat of formation of the carbide Fe_3C checked that of Campbell which result is in error, it follows that Schenck's work must also be in error. Schenck used equilibrium data obtained from a study in which he assumed the solid phases FeO, Fe and graphite to be present. Terres and Pongracey[6] have shown that it is impossible to have FeO and Fe in the presence of carbon monoxide and carbon dioxide without at the same time having some higher oxides of iron occur. Second, their work also shows that solid solutions are formed between these oxides and possibly also with the free iron. These are sufficient reasons for doubting the correctness of Schenck's results below the critical range.

Above the critical range Fig. 1 of this reply, which is taken from Schenck and which represents the results of equilibrium studies of Matsubara, requires that the carbide in pure iron carbon alloys is stable. Attention should be called to the fact that at these temperatures, the partial pressure of carbon monoxide is higher in equilibrium with carbon than it is in contact with saturated austenite and free iron carbide. Also the partial pressure of carbon dioxide is greater in contact with iron carbide and austenite than with carbon.

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[4]Berichte 45, Part I, page 63 (1912).
[5]Jnl. Iron and Steel Inst. No. 1, p. 21 (1901).
[6]Terres and Pongracey, Zeit. fur. Eletro-Chemie, Vol. 25, p. 380, 1919.

That this condition of pressure gradient exists when iron carbide is the stable phase in pure iron carbon alloys may be shown from a consideration of the changes of state necessary for the formation of one formula weight of Fe_3C from the gamma iron of austenite and carbon as follows:

(1) $2\ CO = C + CO_2$. Free energy change $= \Delta F_1 = -RT\ln k_1$

(2) 3 Fe (gamma in Fe_3C austenite) $+ 2CO = Fe_3C + CO_2$
Free energy change $= \Delta F_2 = -RT\ln K_2$

(3) 3 Fe (gamma in C austenite) = 3 Fe (gamma in Fe_3C austenite)
Free energy change $= \Delta F_3$

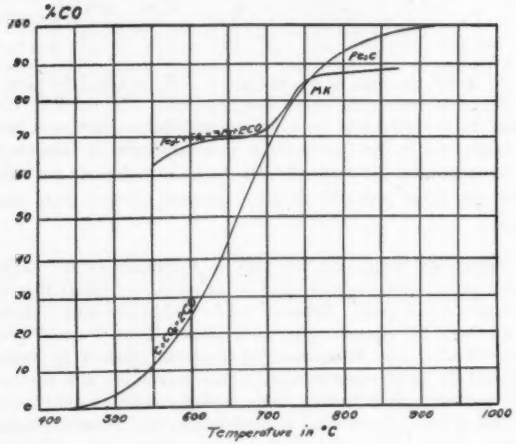

FIG. 1.

Addition of (2) and (3) minus (1) gives

(4) 3 Fe (gamma in C austenite) $+ C = Fe_3C$

Free energy of formation of iron carbide $= \Delta F_4$ or

$$\Delta F_4 = \Delta F_2 - \Delta F_1 + \Delta F_3 = RT\ (\ln K_1 - \ln K_2) + \Delta F_3.$$

Now if Fe_3C is the stable phase, the free energy content of the (C austenite) and of the carbon from which Fe_3C is formed is greater than the free energy content of the Fe_3C, i. e., ΔF_4 is negative. Furthermore, ΔF_3 must be positive. This latter conclusion may be reached as follows:

The solubility of a constitutent from a metastable system is always higher than from a stable phase. If Fe_3C is the stable phase, austenite saturated with carbon from carbon contains more carbon than does austenite saturated with carbon from Fe_3C. This being the case, the concentration of gamma iron in (C austenite)* would be less than it is in (Fe_3C austenite).* Since energy is required to transfer a constituent from a lower to a higher concentration ΔF_3 is positive if Fe_3C is the stable phase. Going back to a consideration of the relation

$$\Delta F_4 = \Delta F_2 - \Delta F_1 + \Delta F_3 = RT(\ln K_1 - \ln K_2) + \Delta F_3$$

the following conclusions may be reached.
ΔF_4 is negative since Fe_3C is assumed to be the stable phase and ΔF_3 is positive, therefore ΔF_1 must exceed the sum of

$$\Delta F_2 + \Delta F_3 \text{ or}$$
$$\Delta F_1 > \Delta F_2 \text{ and}$$
$$K_1 < K_2 \text{ or}$$
$$\frac{P_1\text{—}CO_2 \quad P_2\text{—}CO_2}{P_1^2\text{—}CO \quad P_2^2\text{—}CO}$$

From which it will be seen that a pressure gradient of CO should exist from carbon to Fe_3C and of CO_2 in the opposite direction.

Considerations exactly similar to these will show that if Fe_3C is assumed to be the metastable phase that $K_2 < K_1$ or that the direction of the pressure gradients are reversed.

It would indeed be remarkable if any other relation should exist, for it is evident that perpetual motion would be the result of such a state of affairs. Thus the following general principle has long been recognized. All possible mechanisms by which a given spontaneous change of state may be brought about must operate spontaneously in such a manner as to bring about the same net change whether the change be brought about by one or by a combination of a dozen different processes.

The status of the experimental proof of the stability of iron carbide in the pure iron carbon system seems to be as follows: Below 700 degrees cent. it is metastable. This is in agreement with graphitization experiments carried out in this laboratory and also with equilibrium studies of Dr. H. L. Maxwell. It is also in agreement with Schenck's results.

At temperatures from 900 degrees cent. up to about 1000 degrees cent. Harry P. Evans in this laboratory has succeeded in graphitizing pure iron carbon alloys by using carbon monoxide carbon dioxide gas mixtures as a catalyst.

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*The expression (C austenite) and (Fe_3C austenite) are used to represent austenite saturated with carbon from carbon and from Fe_3C, respectively.

In accordance with the foregoing theoretical treatment this experimental fact is considered a definite proof that Fe_3C constitutes a metastable phase at these temperatures. It also constitutes a direct contradiction of Matsubara's work as presented by Schenck for these higher temperatures. Any statement regarding the stability of Fe_3C in the pure iron carbon system for the temperature interval 700 to 900 degrees cent. will be deferred until the completion of Mr. Evans' work. However, if it is found possible to graphitize free iron carbide in pure iron carbon alloys within this temperature interval, the conclusion must be reached that the carbide represents a metastable phase in this temperature interval also.

Attention should be called to the significance of attempts to graphitize pure carbon alloys, where graphitization does not result. It is a well known fact, for example, that a mixture of hydrogen and oxygen is an extremely metastable system at ordinary temperature. However, if a mixture of these gases be set away for years and the temperature be not raised too high, no appreciable combination takes place because reaction velocities are too slow. Thus their failure to combine is not a proof of their stability though their combination would have constituted a positive proof of their metastability. Suitable catalysts are well known for carrying out this reaction and the metastable character of this mixture at this temperature has been proven.

In exactly the same manner Mr. Schwartz' experiment of heating a pure iron carbon alloy for two thousand hours does not prove the stability of iron carbide. Positive graphitization would have constituted absolute proof of its metastability.

Whatever may be the facts in regard to the pure iron carbon system, it is true that in white irons the carbide is metastable over the whole temperature range from 1100 degrees cent. down to room temperature.

If it is admitted that temper carbon is carbon and that the cementite in white irons is Fe_3C theoretical considerations similar to those presented in connection with the pure iron carbon system will show that metastability of iron carbide will be accompanied by a pressure gradient of carbon monoxide from iron carbide to carbon and of carbon dioxide in the opposite direction if equilibrium between the gases and the solid phases is approached at appreciable rates.

The experimental fact presented in this paper is that an increase in pressure of the mixture of carbon monoxide and carbon dioxide does accelerate the absorption and decomposition of the iron carbide at 927 degrees cent. where equilibrium of the gases with carbon is rapidly approached.

Certainly this result would not be expected if the curves of Fig. 1 of this reply represented the equilibrium values for these gases with carbon in one case and with free iron carbide in the other for under such a set

of conditions our experimental results would indicate that the action would be accelerated where pressure gradients opposing the action should be set up.

Thus to summarize: Schenck's data as well as that obtained in this laboratory indicate that in pure iron carbon alloys Fe_3C is metastable below 700 degrees cent. This conclusion is further supported by successful attempts to partially graphitize pure iron carbon alloys at these lower temperatures. Essentially complete graphitization of free iron carbide in pure iron carbon alloys has been accomplished in this laboratory by the use of this gas mixture at temperatures in the vicinity of 927 degrees cent. This establishes the metastability of Fe_3C at these temperatures and is in agreement with the foregoing theory. The experimental result at the higher temperature also shows that the results of Matsubara cannot hold at this temperature. The conclusion is reached that even in pure iron carbon alloys at 927 degrees cent. the pressure gradients are in the proper direction to bring about positive catalysis of the transformation of the metastable phase (Fe_3C) into that which is stable (austenite and C). The fact is presented that at temperatures of 700 degrees cent. and below that pure iron carbon alloys graphitize and accordingly the conclusion is reached that this is in complete accord with the conclusion that pressure gradients in the proper directions would result if reaction velocities are sufficiently rapid for an approach to equilibrium between the gases and carbon to be brought about during the cooling process through the critical range. Assumptions made by the authors in considering the results which they obtained in their experiments with white iron are in accord with the behavior of the pure iron carbon system for the two temperature intervals concerned. Statements in regard to the behavior of pure iron carbon alloys for the temperature interval 700 to 900 degrees cent. are withheld until work, which is now in progress is completed but the writer considers the known metastable character of iron carbide in the white irons over this temperature interval to be a strong indication that Fe_3C is metastable at these temperatures in the pure iron carbon system and that graphitization of free iron carbide should take place in the presence of a suitable catalyst.

Mr. Schwartz suggests that carbon may migrate from solid solutions of higher to those of lower carbon contents as carbon monoxide rather than as C, Fe_3C or other solid forms. The writer wishes to state that such a thing is entirely possible. Yet the fact should be kept clearly in mind that if the gas equilibrium curves are in the relative positions indicated in Fig. 1 of this reply for temperatures above about 750 degrees cent. pressure gradients of the gases would be in the wrong direction to promote graphitization even if the actual reactions between the gas phase is with solid solutions rather than with free iron carbide and free carbon. If Fe_3C is the stable phase as is demanded by this figure, austenite in contact with carbon would be richer in carbon that austenite in contact with Fe_3C and the result would be that in the presence of carbon, austenite and

carbon would react to form free iron carbide. Such a suggestion by Mr. Schwartz only further emphasizes his failure to appreciate the fact that carbon must be transported from the metastable to the stable phase in any spontaneous process whether it migrates as carbon as carbon vapor or by means of such a carrier as a mixture of carbon monoxide and carbon dioxide.

It is due to his lack of understanding in this regard that he has inserted a modified diagram for white iron in his work[7] which requires iron carbide to be metastable, and again on page 230 of the same work has reproduced Matsubara's equilibrium curves which demand that iron carbide be stable. It is especially significant that he suggests that both these figures may be used to explain the graphitizing behavior of white iron.

DISCUSSION

CHAIRMAN TOUCEDA: This paper and discussion is more or less academic as far as the chairman is concerned. He cannot possibly conceive how it could be put to practical application, but from an academic standpoint, it is interesting. If any one cares to discuss the matter, we ought to afford occasion and opportunity for the author to discuss it. Mr. Hayes, as far as your answer to Mr. Schwartz is concerned, that would require a written review of what he has expounded there.

A. HAYES: Mr. Chairman, I would like to defend my use of the term "catalysis."

Our concept of catalysis and the interaction of these gases is this: Supposing we introduce a molecule of carbon dioxide in contact with a free iron carbide particle. It reacts with the carbon and iron carbide and forms two CO molecules, two carbon monoxide molecules, and these carbon monoxide molecules diffuse over the carbon spots and one of the either of them drops out carbon, gives us the oxygen to the other one and forms CO_2 again. That CO_2 diffuses back over to iron carbide and we have back the CO_2 equivalent with which we started.

In the discussion of catalysis, you will find there are two principal theories for the action of catalysts: One we call the intermediate compound formation theory. It seems to me this is one case where the people working on theories of catalysis have been actually able to isolate the intermediate compound that carries on the catalysis, whereas in many cases where intermediate compound formation and catalysis is assumed, they have never been able to isolate the intermediate compound.

The other theory of catalysis is that known as contact catalysis or adsorption, which of course wouldn't be applied in this case.

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[7]Schwartz, H. A., American Malleable Iron, p. 51, Penton Pub. Co.

There are a number of other points regarding catalysis that merit discussion, but I know that this is extremely technical in its relation to pure physical chemistry itself and I think it will do just as well to submit a complete written discussion.

CHAIRMAN TOUCEDA: I would like to ask you, Mr. Hayes, a question: You ignored the question that carbon was being eliminated during this period.

MR. HAYES: Entirely?

CHAIRMAN TOUCEDA: No. There is a tendency for the carbon to escape in part. That you have ignored.

MR. HAYES: That was the thing in connection with the explanation of the action of these gases being more pronounced in the critical range at the high pressure than at the low pressure. We believe, in fact, that graphitization would proceed in the absence of these gases. When we let these gases come to equilibrium at higher temperature with the carbon and iron carbide, they are richer in carbon monoxide than they are at lower temperatures. Thus, with a sliding temperature, they are too rich in carbon monoxide to be in equilibrium with carbon even if reaction velocities were rapid enough to allow it, with a stationary temperature, which they are not. Thus we have the condition you attempt to set up if you wish to introduce a "case" into a piece of steel. You will submit the steel to a gas mixture that is rich enough in CO so as to introduce more carbon.

Our explanation of the action in the critical range is simply this: that there is a tendency there for graphitization to take place more rapidly in the absence of either than by either of these pressures of gases. Also, the high pressure gases are more rapidly carbonizing through the critical range than the low pressure gases. This is what I assumed would be inferred from the explanation given in the paper.

CHAIRMAN TOUCEDA: I think your opinion regarding catalysis is correct.

Wage-Incentives—The Group-Bonus Plan

By B. R. Mayne,* Saginaw, Michigan

To satisfy the human desire for the dollar, has been and still is, the trying question for every plant manager. As a means of satisfying this desire, group bonus allied with individual bonus, is the solution.

Everyone is familiar with the advantages and incentives as presented by individual bonus. It may be difficult to see these same advantages, namely, increased production, quality of product and satisfied men existing under a group bonus system of payment, nevertheless, let us see if these conditions do exist by analyzing the various groups which are at present operating under this group bonus plan in our foundry.

The malleable iron plant of the Saginaw Products Co. is engaged entirely in the founding of automotive castings for several automobile manufacturers. The demands from the customers for malleable castings include a great variety of parts, but this variety may be termed uniform to a great degree. Every car produced carries the same variety of malleable castings, consequently, as car production increases, the variety of work remains the same, and only the volume of work increases. Therefore, it can be seen why group bonus is applicable to this type of work.

The Unit of Measure

At our malleable iron plant there are at present seventeen groups in operation under the group bonus plan, and all are controlled by the same *unit of measure* for work done, that unit is per 1,000 pounds of customers good castings, which is a daily figure from the daily foundry report, and this report is complete within thirty-six hours from the time the last casting is poured for that day.

Before going into details concerning the various groups, it is quite necessary to illustrate how and when a bonus should be paid

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to a group. To establish a hypothetical group will best serve as an illustration.

Assume for example any one foundry operation which requires sixteen men, working ten hours per day, to complete this operation thoroughly and in such a way as to keep pace with the daily production of eighty tons of customers good castings. At once a unit of measure must be established and that unit will be per 1,000 pounds customers good castings. Under the foregoing assumption there has been applied to this operation 160 actual working hours and the average weight handled per day has been 160,000 pounds.

Here is a direct relation between tonnage and actual man hours, which in this case is 1.0 hours per 1,000 pounds of customers good castings. This has been strictly on a day work basis with an hourly rate of $.40; thus, the direct labor cost would be $.40 per 1,000 pounds. All concerned are well satisfied that the men are giving a fair day's work at the present rate, but feel quite certain that they could not get this operation done more rapidly without the addition of more men, also tools and floor space, or an increase in the hourly rate, with no assurance that the time would be decreased.

As an attempted solution group bonus is applied upon an efficiency basis; therefore, an allowed number of hours must be given to do this work, and this is called standard time hours, against which the actual hours are compared in a ratio of standard time hours to actual hours. This gives a percentage ratio, which applied to a table of percentage efficiencies as shown in Table 1 gives the amount of bonus to be paid.

It will be noted that bonus payment begins at 75 per cent efficiency. In the above case the management deems it worth while to pay a premium for more rapid operation, but still maintain a fixed cost, not to exceed $.40 per 1,000 pounds of customers good castings.

Instituting Bonus Plan Requires Diplomacy

To institute group bonus care must be taken and good salesmanship practiced upon the particular group to be so started. So often it is mistaken as a ruse to exact a little more from the em-

ployees with no proportionate return for themselves. First, leave the hourly rate the same; set the standard time hours in this case at .74 hours per 1,000 pounds, or a total of 118.4 allowed hours per day, at the average tonnage of 160,000 pounds.

It is quite obvious that the group still maintaining their same pace of 16 men for ten hours a day would be 74 per cent efficient

Table 1

BONUS TABLE PRODUCTIVE WORKERS

Eff.	Percent Bonus	Eff.	Percent Bonus	Eff.	Percent Bonus
75	1.	117	40.4	159	90.8
76	1.6	118	41.6	160	92.0
77	2.2	119	42.8	161	93.2
78	2.8	120	44.0	162	94.4
79	3.4	121	45.2	163	95.6
80	4.0	122	46.4	164	96.8
81	4.6	123	47.6	165	98.0
82	5.2	124	48.8	166	99.2
83	5.8	125	50.0	167	100.4
84	6.4	126	51.2	168	101.6
85	7.0	127	52.4	169	102.8
86	7.6	128	53.6	170	104.0
87	8.3	129	54.8	171	105.2
88	8.8	130	56.0	172	106.4
89	9.4	131	57.2	173	107.6
90	10.0	132	58.4	174	108.8
91	11.0	133	59.6	175	110.0
92	12.0	134	60.8	176	111.2
93	13.0	135	62.0	177	112.4
94	14.0	136	63.2	178	113.6
95	15.0	137	64.4	179	114.8
96	16.0	138	65.6	180	116.0
97	17.0	139	66.8	181	117.2
98	18.0	140	68.0	182	118.4
99	19.0	141	69.2	183	119.6
100	20.0	142	70.4	184	120.8
101	21.2	143	71.6	185	122.0
102	22.4	144	72.8	186	123.2
103	23.6	145	74.0	187	124.4
104	24.8	146	75.2	188	125.6
105	26.0	147	76.4	189	126.8
106	27.2	148	77.6	190	128.0
107	28.4	149	78.8	191	129.2
108	29.6	150	80.0	192	130.4
109	30.8	151	81.2	193	131.6
110	32.0	152	82.4	194	132.8
111	33.2	153	83.6	195	134.0
112	34.4	154	84.8	196	135.2
113	35.6	155	86.0	197	136.4
114	36.8	156	87.2	198	137.6
115	38.0	157	88.4	199	138.8
116	39.2	158	89.6	200	140.

or still earning $.40 per hour. The next period, suppose they are 100 per cent efficient, this pays a 20 per cent increase or a total of $.48 per hour, but only over a shorter time. The total money paid in the case of 100 per cent efficient is $56.83 (118.4 actual hours per day x $.40 plus 20 per cent bonus) per day direct labor cost.

In the case of the 74 per cent efficient or day work proposition it was $64.00, consequently, the employees are given an increase

of $.08 per hour, while the management has reduced direct labor cost $7.17 per day with a cost of 1,000 pounds of customers good castings of $.355. This last mentioned figure may then be established as a standard cost, as for any efficiency above 100 per cent this cost per 1,000 pounds remains constant To illustrate, suppose the group efficiency was raised to 120 per cent, this means that 98.6 actual hours have been put in total by the group at the rate of $.576 per hour or a direct labor cost of $56.85 per day or $.355 per 1,000 pounds of customers good castings.

Employee Receives Guaranteed Hourly Rate

Under the bonus wage plan an employee receives a guaranteed hourly rate which is set at a fair point for the community, and for the class of work done. The bonus system gives the group of individuals an opportunity to increase their hourly earnings to a predetermined scale of payment. Payment of this bonus is made at the end of a two weeks' pay period and one pay check includes the hourly base rate for the total actual hours and the per cent of this total according to the efficiency maintained throughout the pay period.

Check Sheets Used

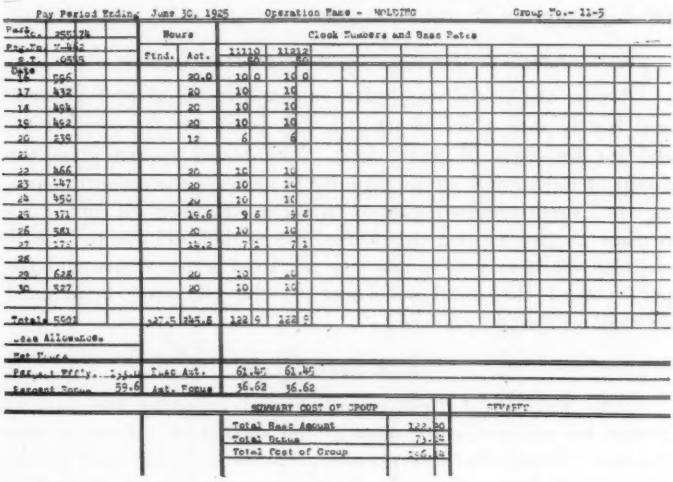
The method of time recording and crediting the various groups for units of work done is first started by a foundry time checker. Group check sheets are prepared daily for each group. These check sheets carry the list of man numbers and the actual hours worked for that particular day. The group check sheets are forwarded to the payroll department in conjunction with daily credits or units of work done which is given out by the production department.

The payroll department then lists the clock card numbers of the men in the group on what is called a group bonus card, and the actual hours of each man employed in this group is posted daily, the total of each day being taken and carried forward in a cumulative figure. The number of units of work done each day is also entered and multiplied by the standard time hours to get the total of standard credit hours due the group.

Groups in this plant range from groups of two men to approximately fifty men. A better idea of a group bonus card can

be obtained from an example (Fig. 1) taken from the payroll ending June 30th, 1925, and is an actual working condition for a two-man group.

Turning now to the cost end, it will be seen that the bonus card of a group working the entire period on one operation will contain the number of units of work done and also the total



Pay Period Ending June 30, 1925 — Operation Name - MOLDING — Group No.- 11-5

Dept. No.	2501Th	Hours		Clock Numbers and Base Rates	
Pay.Tm	T-462	Stnd.	Act.	11110 .60	11212 .60
S.T.	.0535				
Date					
16	556		20.0	10 0	10 0
17	432		20	10	10
18	458		20	10	10
19	462		20	10	10
20	238		12	6	6
21					
22	466		20	10	10
23	447		20	10	10
24	450		20	10	10
25	371		16.6	9 6	8 6
26	561		20	10	10
27	474		13.2	7 2	7 2
28					
29	628		20	10	10
30	527		20	10	10
Totals	5501	147.5	245.8	122 9	122 9
Less Allowance.					
Net Time					
Pay.Per'd.		Base Act.		61.45	61.45
Percent Bonus	59.6	Act. Bonus		36.62	36.62

SUMMARY COST OF GROUP — TOTALS

Total Base Amount	122.90
Total Bonus	73.[illegible]
Total Cost of Group	[illegible]

FIG. 1

amount of money expended for direct labor, giving an accurate direct labor cost per unit or per pound on that particular casting.

Time Studies Used in Setting Rates

In establishing rates for molding operations both individual and group time studies are made. A rate is given the molder or molders as the case might be, in molds to maintain 100 per cent efficiency, not pieces per hour or money per piece but in molds per hour. The rate, if met by the molder nets him a 20 per cent increase on his base rate. As a further inducement, if a molder maintains an efficiency of 100 per cent or over, for a pay period, his

base rate is automatically increased $.05 per hour, and the resulting bonus payment is computed from this new base rate.

This practice is in force only in the molding department. However, in placing so many molds for 100 per cent efficiency, it is an understood fact that every mold shall produce good castings, the molder sustaining a loss for faulty work as is quite in keeping with all foundry practice.

Time study is also employed in establishing rates for core making. This operation involves no group, all work is individual bonus. Rates are given in pieces or cores per hour to maintain 100 per cent efficiency, the same deduction holding true in the case of careless work as in molding.

Time study of a group operation is not made from individual studies within the group but from the standpoint of the required total production and actual working hours necessary to reach this point with sufficient allowance that this particular group will not become a choke point in production. Preliminary to establishing a group standard time considerable care must be taken in working out an efficient plan of group operation with a logical arrangement of equipment and material. Then with an organized group they are ready to be placed upon an efficiency basis for measuring their skill and speed of operation. Daily efficiency figures are issued to the various groups, which also carry a cumulative efficiency to the last date, as well as the daily efficiency, giving a very graphic picture to the groups as to their progress towards earning more money.

Core Room Work Carried on by Three Groups

In the coremaking department, all contingent labor is carried by three groups, namely, core room labor, core delivery and core assembly. The first named group, core room labor, is composed of both male and female workers, numbering about twenty-six in total. The operations of this group are quite numerous and varied, consequently they are subdivided, but are maintained as one group to facilitate many changes of work during the day with no time checking necessary.

The first subdivision includes all labor necessary to the coremakers benches. The following are the operations: sand wheeling to coremakers, carrying away green cores, wire cutting, rod cutting and salvage, chill sorting and inspecting, also keeping all core driers sorted and ready.

The second subdivision includes: sorting of baked cores, cleaning and inspecting, placing cores in core delivery boxes, and removing cores to core storage compartments.

Core delivery is the next group. This operates under the present schedule of production with ten men. This operation is more distinct as it includes only delivery of cores to the molders' floors and the returning of the empty core delivery boxes to the sorting group. It calls for six men working days and four men nights.

The third group, core assembly, is a five-man group. This group, however, is based upon hourly piece production with a specified rate of cores assembled per hour for all five men to be 100 per cent efficient. The operations include: jigging, filing, venting, and pasting of two halves to form one core, with one man on each of the above operations.

Foundry Groups

The foundry proper operates with three separate groups, one group pouring iron, one shifting weights and molds, and the third operating bull ladles of 350 pounds capacity traveling on a monorail. The number of men on the pouring group varies directly with the tonnage. At the present the group contains 28 men, pouring four heats per day. This comprises about 40 per cent of the total working hours. The remaining 60 per cent is classed as foundry labor and is a straight day work proposition, which includes foundry clean-up, trimming and trucking of castings to a central point where all sprue is broken, the cutting and conditioning of sand piles between the morning and afternoon heats.

This arrangement is advantageous from the fact that it permits continuous molding throughout the heats with no decrease in production, giving approximately 1,250 pounds of customers good castings per day per molder.

Night Work on Bonus

Night foundry work is carried as a group bonus operation from the fact that a certain specified amount of work must be done previous to the next day's heat. The labor is identical with the foundry labor previously mentioned. This group is dependent upon no other factor than its own working hours, where in the former case, the amount of labor between heats can not be controlled as that is dependent upon furnace operation.

Melting Bonus Based on Oil Consumption

Melting is also a bonus proposition, but the standard for operation in this instance is based upon oil consumption in gallons per ton of metal melted. Oil consumption is taken from the time the furnace is fired until the furnace is completely poured off. A fixed number of gallons per ton melted is the standard rate of oil consumption.

The ratio between the standard rate and the actual gallons per ton melted is the resulting efficiency of that particular furnace. The men's earnings are increased consequently by the economy of operation. This plan has netted a tremendous saving in fuel oil and decreased the amount of refractories used in furnace repair.

Hard Iron Room in Three Groups

Hard iron milling, sorting and grinding are operating as three separate groups with a standard time rate per 1,000 pounds of customers good castings for each group.

All hard iron scrap is taken out during these operations and the proper deduction is made for molders' loss, etc. The total scrap is then deducted from the total poured per day and the weight of customers good castings is thereby determined daily.

Continuous Tunnel Kiln Aid Bonus on Annealing

Annealing is done by means of a continuous tunnel kiln, castings being packed in pots, placed on cars and moved to a charging line. At one end of this line cars are also unloaded from the discharge lire. This group operates with a minimum of 14 men

with a standard time rate in hours per 1,000 pounds of customers good castings and with a differential credit in standard hours for all tonnage over 800 tons annealed per day period. This has a tendency to encourage better and closer packing which is a requisite to good annealing.

The soft iron mills for cleaning after annealing are also on a similar tonnage basis for castings milled and delivered to the shipping department. This group is composed of fourteen men, seven working days and seven nights.

The soft iron cleaning also includes all sand blasting for which there are two mills. Both day and night crews are paid the prevailing efficiency bonus as earned by the entire group, inclusive of the sand blasting.

Shipping Department Efficient

The shipping department makes all necessary finishing operations contingent to turning out good commercial castings. This group averages from 30 to 50 men, varying with the plant production. The operations are quite diversified, but with all the men on these various operations working to one end, that of keeping the total actual hours per day as low as possible, thereby maintaining a good efficiency. In this department all sorting and bagging is done, all straightening, swedging and gauging, all drop hammer and hydraulic press work on heavier castings, in fact, everything necessary to produce a finished product.

Foreman Bonus

Another step forward has been taken by the management and the foremen of the different groups have been placed in a group to enable them to increase their monthly earnings. This group is not operated or controlled by production but by the total of three costs: productive labor, expense labor and expense material.

The lowest total for the above three accounts was established as a standard cost, any figure below this resulted in a definie percentage increase in earnings and established on a scale giving a greater return to the foremen for a consequent further reduction in these three items. It is hardly necessary to relate the direct

results. The percentage of scrap loss in hard iron decreased between 35 and 40 per cent and the aggregate of the three cost accounts has never been over the standard established. Further, the foremen have increased their monthly earnings from 8 to 12 per cent with an obvious saving to the company.

Summary

The group bonus plan of wage payment has been used at the malleable iron plant of the Saginaw Products Co. for about four years. Various changes have occurred and in some cases it was found impractical to carry certain operations on a group bonus plan, and several objections can still be raised. Necessary to the working of a group bonus plan there are a few prime requisites, otherwise, day work proves the most adaptable. First, the groups must be logically arranged as to operation, which are as near repetitive as possible. The foreman as well as group individuals must be 100 per cent sold on the idea. The standard time rate should be established only when increased efforts by the group begin to yield a return, and a bonafide assurance that no change will be made in standard time rates for a definite period, thus, they are guaranteed their earnings regardless of how great the increase for at least one pay period. It is quite necessary that the groups be given periodic statements as to their status, these statements carrying a daily efficiency with actual and standard group hours, also a cumulative efficiency including the date of issue, consequently, at the end of the pay period a group statement carries the efficiency at which the group will be paid.

The plan of group bonus wage payment as maintained by the Saginaw Products Co., malleable iron plant, has resulted in increased production throughout the plant, decreased work in the payroll department, an accurate check on all men with the resultant opportunity to weed our laggards, assisted the employment department by allowing them to guarantee an applicant for work a fair and just day rate, and has given the company a satisfied working force, thereby reducing labor turnover.

DISCUSSION

R. E. BELT: I think the bonus plan of the Saginaw Products Company is very successful for them, more so than it would be in a regular jobbing house.

CHAIRMAN E. TOUCEDA: You don't think it would be as practicable in the regular jobbing foundry?

R. E. BELT: No, not in a foundry partly on a jobbing basis because the Saginaw Plant can produce more regularly than in a jobbing foundry and such production greatly facilitates the operation of any bonus plan.

W. M. THOMAS: We have a bonus plan at the Union Malleable Iron Company that we are working out. It has been working now for about a month. We wanted to stimulate our production and attendance and probably the main reason to cut down our scrap. We made our molding department this proposition: First, that they have a perfect attendance of two weeks and then, starting with a 5 per cent scrap, we promised a return in the form of a bonus, and so on down until we reached the very limit; that is, no scrap at all. We offered a fairly substantial bonus for that. It was all worked out on a two-week basis.

This hasn't been going on at our place for a great while, but we have stimulated attendance and we can see results in our reduced scrap and also results on production of our men. This has been done covering a period to see just what results we can get and so far they are favorable. We are pleased with this little plan.

F. L. WOLF: At the Ohio Brass Company's malleable plant we have a bonus plan in which we have the foundry divided and the men classified in groups with instructors. The instructors are paid a salary and a bonus. Mr. Marr, who is our malleable superintendent, can tell us about it more in detail.

W. M. MARR: The saving is involved primarily in a system of checking and recording of losses back to the individual who makes the scrap. The instructor is the means by which the information is gotten back to the molder. There is a bonus coming to the instructor over his base salary, depending on the percentage of work which he saved.

A system by which the scrap is all chartered daily is primarily the means and the tool that serves as a clearing house and gives him the story of the work as it goes through the foundry. I think primarily that it is the system by which the work is recorded rather than the bonus that gives us the low scrap report.

MR. PERRY: Is this scrap reported per man so that he will have the incentive and others will see who did it, or is it by department or group?

W. M. MARR: The molders are divided under four instructors and each instructor has a separate sheet and these sheets are all posted together on a board. We get the little competition that necessarily rises when one instructor is down to 20 per cent loss and another up to six. On each instructor's chart is recorded each molder, pattern number and molder's number, the pieces molded and the distribution of the scrap under the various scrap headings. The complete story of each man's work of the previous day under each instructor is on that board. The day after the work is done it is reported back. A lot can be gained by the immediate reporting of this scrap. I think the speed has a lot to do with the efficiency of it.

I would say this. After all, it is merely telling a man immediately when he is wrong and showing him the other fellow can do better. We have had a highly competitive struggle between the molders and the instructors to be the best. We use red pencil and blue pencil in keeping the record. When a molder goes over five per cent he starts in red pencil. We save a lot of money and real castings in getting this before the men and before the instructors. Nobody likes to be shown up poorly as compared to someone else.

F. L. WOLF: I might add just one thing we have done. We have a bulletin board right behind the furnace where everybody can see it. Each instructor's losses are plotted every day. Every man in the foundry can see it.

L. J. KELLY: Our shop turns out primarily railroad work. Most of it is of a miscellaneous character. We have tried all kinds of bonus plans for scrap but for the amount of production we have they did not help us out much. We have tried all kinds of schemes and we found by paying the molder a fair price so he can make a day's wages, he will do his best without any bonus.

We tried this higher pay scheme during the war and found we gained fifteen to twenty per cent on production. As to scrap, you gentlemen know if you plot it closely that the actual scrap a molder makes is pretty low. Of course, there are cracks and slag defects that the molder is not to blame for. Those have to be taken into consideration in any kind of a bonus plan. If the pattern is made so the molder can't make much scrap, you will find it is pretty low. Where the piecework plan can be worked to advantage, we do it. Our production, I know, under normal conditions compares with the average.

With the bonus plan we tried to give a man a ten per cent increase for continuous work and things like that but after a while we thought he was entitled to it whether he came up to efficiency figures or not. So we try to pay a fair rate on every job and then he will turn out the work.

MR. REESE: We have been working on a bonus plan for two months now. We have already started in one department. Our bonus depends upon co-operation similar to the bonus described here.

Up to two months ago we had eleven men working in our chipping department and we reduced the number to seven and expect the seven men to produce the same amount that the eleven men had done previously. Our efficiency in this bonus plan is set at seventy-five per cent. We started at eighty per cent, which will guarantee the men their hourly rate and give them a chance to earn a bonus on top of the regular rate.

We started two months ago and we figured that the men should earn a bonus between twenty-five and thirty-five per cent. The men so far have been earning about 18 per cent bonus from the second month. We had some trouble getting started the first month. We are dealing with the ordinary foundry type of labor, the foreign element. It is very difficult and hard to talk bonus to these men but we are finding that we are getting more cooperation from the men and it looks as though our bonus may succeed. The efficiency, as I said, is based a little higher than the efficiency plan described. That means we are able to cut down the cleaning costs at once 20 per cent. It previously took us three and one-half hours to chip a thousand pounds of gray iron.

We established gray iron as our standard and then we took a factor. We drew graphs for gray iron, steel, and brass work. We found it took three and one-half times as long to chip one thousand pounds of steel as it did a thousand pounds of gray iron. We also clean by tumbling barrel and sand-blast. We figured out the ratio of time it took to tumble and sand-blast.

Our bonus plan is based on previous records. We have taken our company's record for the past two or three years, especially the last year. The records for the last year are the real records by which the bonus is set but the previous years give you the idea whether to set our efficiency at eighty per cent or seventy-five per cent. We are planning to give the men a little incentive on the scrap proposition, so that the three high men will get a little extra bonus each month.

I was wondering if any men here have paid a bonus on tonnage, the number of pounds scrap and the number of pounds good.

W. M. MARR: We find in our plant the variable between per cent pieces and per cent weight doesn't vary a half per cent. You can take it either in pieces or in weight and you will land somewhere within a half per cent invariably.

I want to add something to Mr. Kelly's remarks. In assuming that molders are not at fault for losses, that is an assumption that should not be used because if you do get into foundry losses, there is an excuse

for almost anything. It is a safe thing to assume that it somebody's fault that a casting is lost and you will find out how. There are reasons for these things, but those are the things you want to cure. If you look for the reasons for castings being no good, you will find all kinds. If you put the thing down as a matter that the foundry shouldn't bear any losses and the foundry should be paid on the basis of good work done, that will clear up a lot of these losses.

M. J. LEFER: I would like to know if in the scheme of the Ohio Brass Company the molder reaps some of the benefit as well as the instructor.

W. M. MARR: No, sir, the assumption is that the job is priced at a rate that gives the molder so much for making a casting good—straight piecework. The molder gets his earnings by not having any loss.

A Consideration of the Annealing Operation in the Malleable Foundry

By C. J. McNamara* and C. H. Lorig,** Milwaukee, Wis.

The conversion of white cast iron into a malleable product is dependent upon a number of factors. The chemical composition of the iron, the temperature and time of the annealing process, the rate of cooling the iron from the temperature of anneal until it has passed through the transition point are all influential in determining the quality of the resulting product. These factors are inter-dependent and their relation to each other has been subject to much investigation.

Scope of Paper

In this paper the authors wish to present a few simple experiments that were carried out with the object of obtaining some knowledge of the rate at which white iron graphitizes. Two sets of wedges cast from different heats of an oil fired melting furnace were selected as test specimens. As a general rule the test pieces were of similar size; yet this feature is not essential as they were subject only to microscopic examination. The wedges were packed in sand blast sand contained in an 1¼ x 7-inch nipple capped on both ends. One wedge from each heat was packed in each container in order to make a comparison between the two sets of wedges which have been given identical heat treatments. The analyses of the test wedges is that which is representative of the heat from which they were cast. The analyses and the means of designating the two sets of test pieces are as follows:

	Si	*Mn*	*C*
H2-17	1.02	0.30	2.55
H1-20	.86	0.25	2.69

In the first experiment fourteen of the containers into which wedges were packed were placed upon a stack of pots close to

*, **Superintendent and Metallurgist respectively, The Stowell Co.

the front of an annealing oven. An opening in the brick work of the front wall opposite the containers made possible their extraction by inserting a long pair of tongs. Into this opening was also placed a thermo-couple with its hot junction extending to the center of the pile of containers. By means of a pyrometer temperature readings were taken each hour. When the temperature of 1550 degrees Fahr. was registered on the pyrometer the first of the containers was removed from the oven and then quenched in water to preserve structural conditions as they actually existed at the high temperature. Other containers were removed from

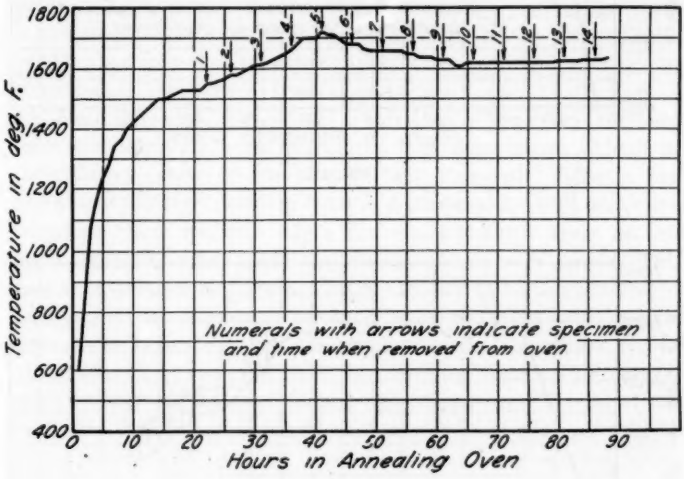


FIG. 1

the oven at intervals of five hours. The temperature readings and the time each container was removed from the oven is recorded as the graph of Fig. 1. Due to the location of the specimens the graph indicates temperatures that are considerably above the average oven temperature of 1550 degrees Fahr. They lay directly in the path of the hot gases arising from the combustion chamber as the gases swept over the top of the annealing pots.

The second experiment was a repetition of the first except that the containers were located in the cooler portions between

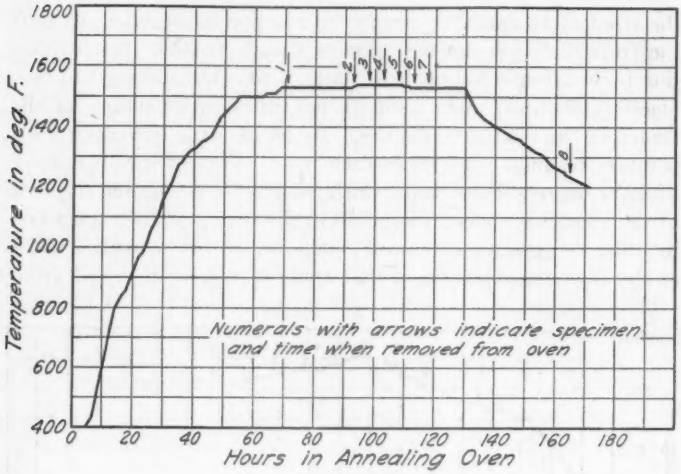

Temperature in deg. F.
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
120
140
160
180
Hours in Annealing Oven
Numerals with arrows indicate specimen and time when removed from oven

FIG. 2

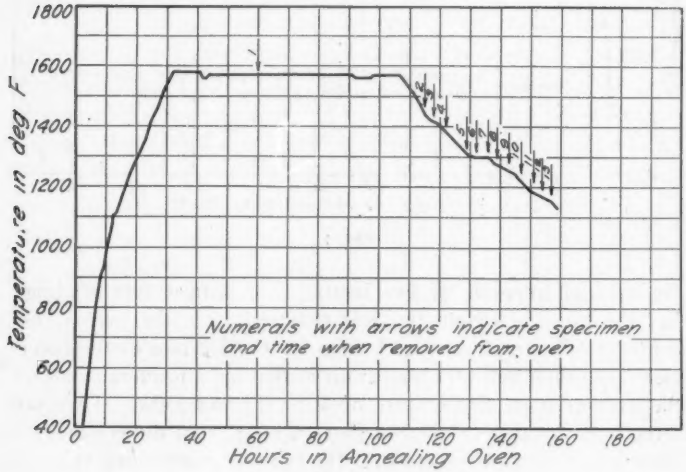

Temperature in deg F
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
120
140
160
180
Hours in Annealing Oven
Numerals with arrows indicate specimen and time when removed from oven

FIG. 3

the pots near the floor of the oven. And in a third experiment the containers were removed from the annealing oven during the cooling period of the annealing cycle. The graphs of Figs. 2 and 3 record the temperature readings and the time each container was removed from the oven during the second and third experiments.

General Discussion

Graphitization begins very soon after the temperature rises above the transition point. In the early stages the reaction proceeds rapidly, but gradually slows down as the equilibrium point is reached. This occurrence is illustrated in the micro-photographs shown on the following pages. They represent microscopic structures of specimens from experiments 1 and 2. In Figs. 4 and 5 are shown photographs of the first set of specimens removed from the annealing oven during the first experiment. Much of the primary cementite has already been removed. After a few more hours in the annealing oven at a temperature well above the transition there remains only a few small globular areas of primary cementite which undergoes decomposition very slowly. This fact is illustrated in Figs. 6, 7, 8, 9, 10 and 11 which are microphotographs of specimens removed from the oven after certain intervals of time. Fig. 6 is a microphotograph of specimen H2-17 of the second set removed from the annealing oven during experiment 1. Fig. 7 is a microphotograph of specimen H1-20 of the third set; Figs. 8 and 9 are microphotographs of specimen H2-17 of the fourth and fifth set respectively that were removed from the annealing oven during experiment 1. Figs. 10 and 11 are microphotographs of specimen H2-17 from the first and seventh sets that were removed from the annealing oven during the second experiment.

In Fig. 10 the amount of primary cementite is relatively small when comparison is made with the original white iron, and yet in Fig. 11 there are still a few small areas of undecomposed cementite after an additional 47 hours in the annealing oven. It is this slowing up of the decomposition of cementite that necessitates the long time periods for annealing white iron castings. Just when this reaction is complete is very hard to state with certainty

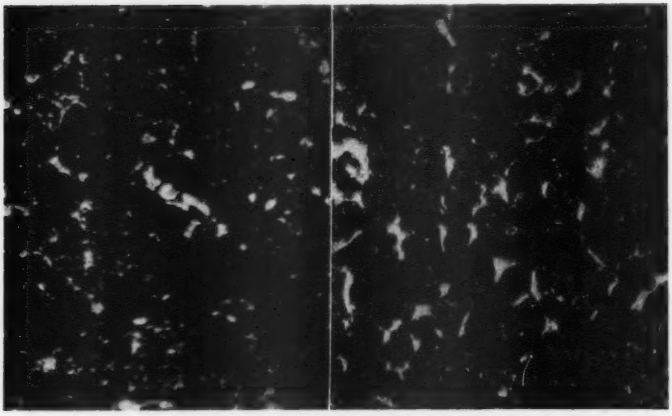


FIG. 4 FIG. 5

FIG. 4—SPECIMEN H2-17—FIRST SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 16 HOURS AT A TEMPERATURE ABOVE 1300°F.—x 100

FIG. 5—SPECIMEN H1-20—FIRST SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 16 HOURS AT A TEMPERATURE ABOVE 1300°F.—x 100

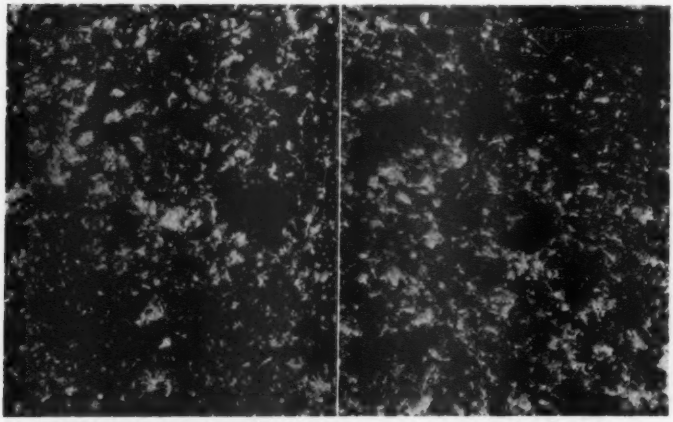


FIG. 6 FIG. 7

FIG. 6—SPECIMEN H2-17—SECOND SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 20 HOURS AT A TEMPERATURE ABOVE 1300°F.—x 100

FIG. 7—SPECIMEN H1-20—THIRD SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 25 HOURS AT A TEMPERATURE ABOVE 1300°F.—x 100

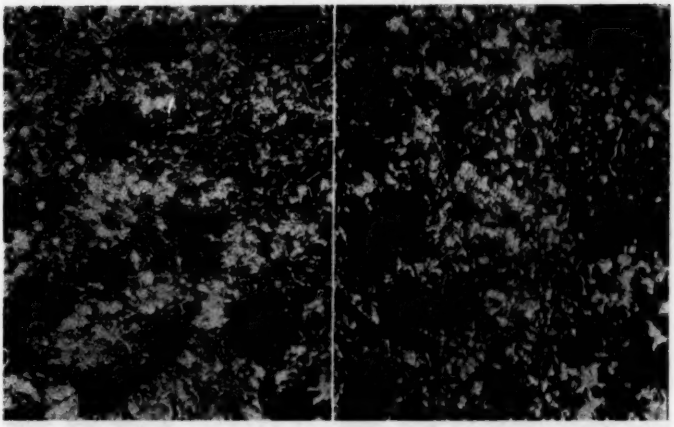


FIG. 8 FIG. 9

FIG. 8—SPECIMEN H2-17. FOURTH SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 30 HOURS ABOVE 1300°F.—x 100

FIG. 9—SPECIMEN H2-17—FIFTH SET. EXPERIMENT 1. REMOVED FROM OVEN AFTER 35 HOURS ABOVE 1300°F.—x 100

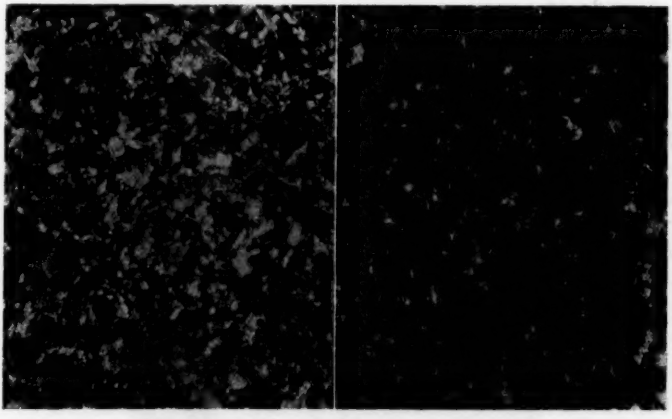


FIG. 10 FIG. 11

FIG. 10—SPECIMEN H2-17—FIRST SET. EXPERIMENT 2. REMOVED FROM OVEN AFTER 33 HOURS ABOVE 1300°F.—x 100

FIG. 11—SPECIMEN H2-17—SEVENTH SET. EXPERIMENT 2. REMOVED FROM OVEN AFTER 60 HOURS ABOVE 1300°F.—x 100

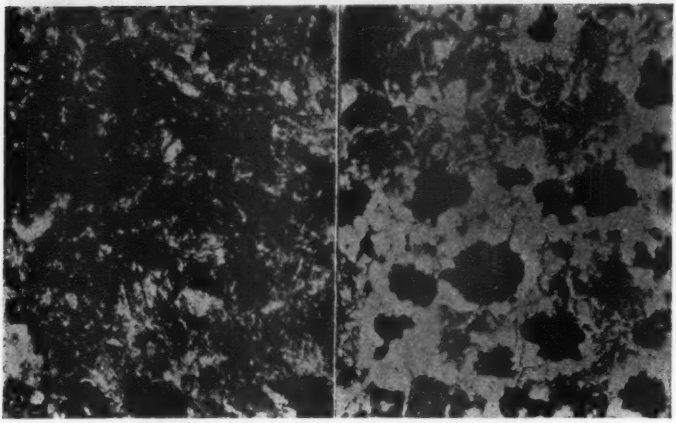


FIG. 12 FIG. 13

FIG. 12—SPECIMEN H2-17—FOURTH SET. EXPERIMENT 3. REMOVED FROM OVEN AT A TEMPERATURE OF 1380°F. AND QUENCHED—x 100

FIG. 13—SPECIMEN H1-20—FIFTH SET. EXPERIMENT 3. REMOVED FROM OVEN AT A TEMPERATURE OF 1310°F. AND QUENCHED—x 100

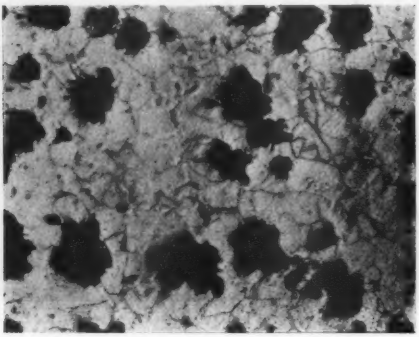


FIG. 14—SPECIMEN H1-20—SIXTH SET. EXPERIMENT 3. REMOVED FROM OVEN AT A TEMPERATURE OF 1300°F. AND QUENCHED—x 100

on account of the meager data available but it may be safely said in the above experiments it would require close to sixty hours at a temperature of 1500 to 1550 degrees Fahr. to insure freedom from primary cementite.

One must not forget that due to the temperature gradient between the exterior and interior of the annealing pot upon heating there is a considerable lag in the time at which the interior is brought to the temperature of the outside. On tests with thermocouples packed within the pots this lag amounted to as much as fifteen hours.

Since the problem of shortening the annealing time for malleable castings is of primary importance it would seem that the above experiments suggest one means in reducing the actual time for the anneal. It is very probable that the last traces of cementite could be removed by overcoming equilibrium conditions. As austenite increases its solubility for carbon with a rise in temperature why should not the small remaining areas of primary cementite pass into solution very quickly if the temperature is raised? At the same time the reaction would be benefited by the increased rate of graphitization with higher temperatures. A hundred degrees rise in temperature should be sufficient for the purpose described.

It would seem that raising the temperature of the oven for a short while before it is allowed to cool would affect the structural and physical properties of the iron but little. The carbon globules have already been formed before the rise in temperature takes place. At the higher annealing temperatures no apparent increase in the ferrite grain sizes have been noticed. No marked variation in the physical properties would therefore be expected by heating the iron for a short time above the usual annealing temperature. It is to be regretted that insufficient data prevent the verification of this point.

In the annealing of malleable castings it is necessary to cool very slowly from the annealing temperature to a temperature slightly below the critical point of the iron. It is customary to cool at a rate of 10 degrees Fahr. per hour although it is possible to obtain good malleable castings when the rate of cooling is as

high as 20 degrees Fahr. per hour. Cooling at a rate above 20 degrees Fahr. per hour is very likely to lead to trouble in obtaining malleable castings of good quality. Precipitation of stable cementite takes place if the cooling rate is too rapid.

The critical point on cooling for the white iron used in the experiments lies close to 1310 degrees Fahr. The three micro-photographs of Figs. 12, 13 and 14 are, first, of the iron before it has passed through the critical range, second, of the iron as it is passing through the critical range, and third, of the iron shortly after it has passed through the critical range. The specimen of which the micro-structure is represented in Fig. 12 was removed from the annealing oven at a temperature of 1380 degrees Fahr. A rapid quench in water preserved the structure which was stable at that temperature. In Fig. 13 the iron is shown as it is passing through the critical range. Each carbon globule is surrounded by an area of ferrite. The specimen from which this micro-photograph was made was removed from the oven at a temperature of 1310 degrees Fahr. and was then immediately quenched in water. A specimen removed from the oven three hours later at a temperature of 1300 degrees Fahr. had a normal malleable iron structure. Fig. 14 is a micro-photograph of this specimen. The critical point for the iron used in the experiments lies very close to 1310 degrees Fahr.

As the last 0.70 per cent* of combined carbon must be eliminated in a few degrees drop in temperature, a decrease in the cooling rate at this time would be beneficial. It has been noticed in plotting a large number of time-temperature graphs for annealing ovens, that from the annealing temperature to a temperature close to the critical point the cooling proceeds at a uniform retarded rate. But when the temperature of about 1320 degrees Fahr. is reached in the coolest part of the oven there is perceptible retardation in the rate of cooling. This retarded rate continues until the hottest portions of the oven have dropped below the critical temperature; then cooling proceeds as it normally had during the early stages. Presumably this arrest in the normal cooling rate can be accounted for by the spontaneous generation

*A. E. White and R. S. Archer. The Annealing of Malleable Castings. Trans. A. F. A., Volume 27, 1920, pp. 351-365.

of heat by the metal as it passes through the critical point. The quantity of heat generated in this manner is sufficient to overcome some of the losses through radiation and conduction and thereby decreases the cooling rate. The iron through its generation of heat during the transformation from the gamma to the alpha state supplies a means for reducing the cooling rate as it passes through the critical range.

Continued slow cooling below the critical point undoubtedly has little purpose in producing good malleable iron. All specimens that were removed from the annealing oven at a temperature below the critical range had the same ductility regardless of the manner in which they were cooled. The specimens quenched in water from a temperature just below the critical range were as ductile as those which were allowed to cool to room temperature very slowly.

To be certain that all the malleable castings in an annealing oven have been converted into the normal product it is better to cool very slowly until the pyrometer records a temperature about 100 degrees Fahr. below the critical point. This will allow the iron in the somewhat hotter interiors of the pots to be cooled below the critical point.

The excessive oxidation of the annealing pots is one bad feature resulting from opening the annealing oven at too high temperatures. The air which is sealed in the oven when it is cooling has had time to come to equilibrium with the iron of the pots. No further oxidation will result as long as the air in the oven is not displaced by a new supply. Upon opening the oven, however, the fresh supply of air which circulates about the pots upsets the equilibrium which had been set up. Excessive oxidation is sure to result if the temperature of the oven is very high.

Conclusion

The results presented above are the correlation of a few months' observations in an effort to obtain some information regarding the graphitization of white iron in a commercial annealing oven.

One of the Causes of Variations in Rates of Graphitization of White Cast Iron

By Anson Hayes* and H. E. Flanders,* Ames, Iowa

The use of any rapid method of annealing white iron in the production of malleable castings essentially amounts to cutting down the factor of safety which is provided by the present long annealing cycle. The use of a greatly reduced annealing period thus necessitates a rather precise knowledge of the factors that cause variations in the rates of graphitization of white cast irons of normal chemical compositions. Hence this study has been made as a part of a program whose purpose is to make feasible the commercial use of a greatly shortened annealing cycle.

Recently a commercial concern who has been cooperating with us in this work submitted to us a sample of white iron whose chemical composition was considered within the limits of that representing good practice in white iron compositions but which failed to respond to a 36 hour anneal and which also failed to give good malleable by the use of the present industrial annealing period.

The examination of the chemical composition of this iron and its comparison with that of some other heats of white iron which had produced picture frame when annealed by the present commercial method revealed the fact that all of these irons were slightly high in sulfur (containing 0.06 to 0.08 per cent) and somewhat low in manganese.

This fact in conjunction with the well-known stability effect of sulfur upon the combined carbon of grey iron led to the rather conclusive experiments with sulfur and manganese which will be reported here.

As far as experience with a number of samples of white iron can be relied upon it seems to be the case that slow graphitizing white iron requires longer time for absorption of the free iron

*Iowa State College.

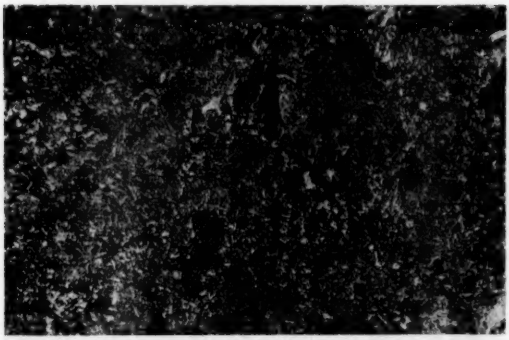


FIG. 1—NORMAL GRAPHITIZING WHITE CAST IRON MELTED AND COOLED IN INDUCTION FURNACE—X 100

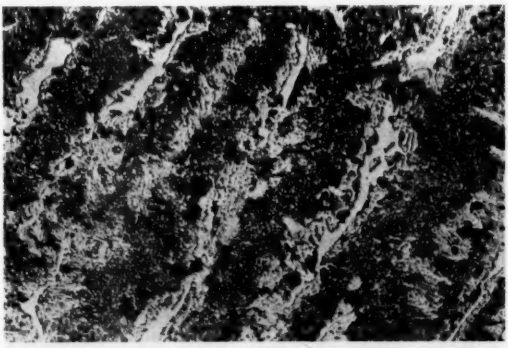


FIG. 2—NORMAL GRAPHITIZING WHITE CAST IRON PLUS 0.02 PER CENT SULFUR MELTED AND COOLED IN INDUCTION FURNACE—X 100. —THE WHITE CONSTITUENT IS FREE IRON CARBIDE

carbide at the high temperature. Slower rates of cooling are also necessary to completely break down all of the combined carbon in such samples.

Thus four or five hours at 927 degrees Cent. is sufficient time at the high temperature to absorb free iron carbide in samples which do respond to annealing cycles of from 20 to 30 hours while this sample which did not respond to such a treatment required more than eleven hours for this change to take place.

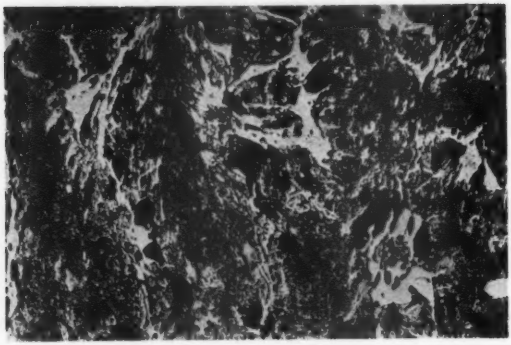


FIG. 3—WHITE CAST IRON RESISTANT TO GRAPHITIZATION MELTED AND COOLED IN INDUCTION FURNACE—X 100—THE WHITE CONSTITUENT IS FREE IRON CARBIDE

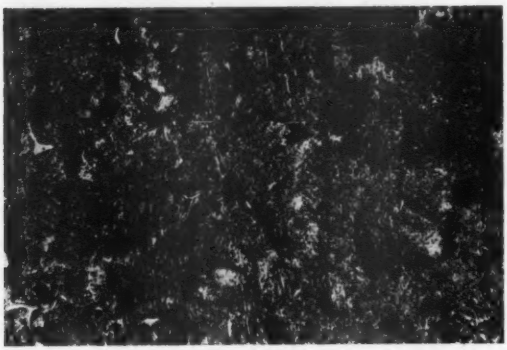


FIG. 4—WHITE CAST IRON RESISTANT TO GRAPHITIZATION PLUS 0.20 PER CENT MANGANESE MELTED AND COOLED IN INDUCTION FURNACE—X 100

In short, the time necessary to absorb the free iron carbide at the high temperature seems to be a criterion as to whether or not the white iron will respond to a short annealing period.

This test should be useful in determining whether or not such a shortened anneal can be applied to any given heat of white iron

but something more important than this is suggested by the results which follow.

A sample of a white iron which did respond to a 26 hour anneal and another sample of the same iron to which 0.02 or a per cent of sulfur had been added were melted in magnesite crucibles in an induction furnace and were allowed to cool with the furnace. Fig. 1 shows the resulting structure of the sample without sulfur added and Fig. 2 is that produced by addition of the sulfur.

Following this one sample of the white iron which did not respond to the short anneal and another to which 0.20 per cent of manganese had been added were melted and allowed to cool in a similar manner. The structures produced are shown in Figs. 3 and 4 respectively.

These samples were then given a 30 hour malleabilizing anneal with the result that the samples of Figs. 1 and 4 malleabilized while samples of Figs. 2 and 3 did not.

This indicates that sulfur has a very great influence upon the rates of graphitizing of white cast irons and that the difficulty in this case can be completely corrected by the addition of a small amount of manganese.

DISCUSSION

CHAIRMAN E. TOUCEDA: In some particulars, this is quite an interesting paper and deals with a subject that should be of interest to all engaged in practical foundry work. There certainly should be someone here who can discuss this paper in a very profitable way, particularly to go over the ground that has been covered in the past in connection with what has been done along that line of control. That is, it has been the purpose of all of the manufacturers of malleable iron for the past ten years to keep very close control of the manganese and sulphur ratio. There ought to be some one here who can enlarge upon that. It is certainly worth the time. Mr. Hayes has devoted quite a lot of time to this particular paper and it ought to receive that recognition.

J. B. DEISCHER: All I can do is confirm Professor Hayes' findings.

J. H. SCHMUCK: I would like to ask Mr. Hayes if he had hot iron analysis.

A. HAYES: Yes. The manganese was somewhere in the neighborhood of .024 to .026 and the sulphur was .083 on the samples which did not respond. On the samples to which sulphur was added and which did respond to the rapid treatment, the manganese was just about .26 and the sulphur about .034.

CHAIRMAN TOUCEDA: There is a certain favorable combination in manganese and sulphur that facilitates graphitization. Whether the process is going to be rapid or long, whether it is a laboratory or commercial experiment, remains to be seen.

J. B. DEISCHER: I would like to ask Mr. Hayes if he has conducted any experiments dealing with high manganese, that is, the effect it might have on it if annealed above .3 or .4. I think it would be interesting, he has, to know what he has found.

A. HAYES: The work that Mr. Flanders has been doing is to make up a whole series of sulphur contents and treat with a whole series of manganese contents and see where the most rapid rate of absorption comes. I was talking to a metallurgist in an industrial plant a short time ago who has conducted a large number of experiments along this line. He finds that whenever the sulphur gets a little too high, he gets a flame. The more sulphur he has, the thicker the flame. If he begins to run up the manganese above .34, he begins to get a flame and the higher the manganese, the thicker the flame. That is the way he recited his experience. Of course, we want to find out how soon manganese will begin to put the flame on. As the metallurgist expressed it, his method was to keep track of the manganese and let the sulphur take care of itself.

CHAIRMAN TOUCEDA: There has been a good deal of work done that hasn't been published in connection with that manganese.

A. HAYES: I am familiar with the fact that E. A. Hammer did some important work early in the industry in determining the proper sulphur ratio. The only reason I thought this particular work might be of interest was the fact I wasn't aware of studies made on rates of absorption of iron carried, in the vicinity of those combinations now considered to be good practice.

Chemical Elements Inhibiting Graphitization

By H. A. Schwartz[1] and G. M. Guiler,[2] Cleveland, O.

It is a well known fact that in essence, the graphitizing reaction involves only iron and carbon, and has as its final result the conversion of cementite into its component elements. It is equally well known, however, that the reaction is affected materially by the presence or absence of other elements. Indeed, the present author has suggested elsewhere[3] that possibly silicon plays an essential part in the reaction. Quite lately, we have carried on experiments on the annealing of nearly silicon free alloys. These contained less than .05 per cent silicon, about .02 per cent phosphorus, .043 per cent sulphur, and .016 per cent chromium. One alloy, washed metal, contained no manganese, another contained .23 per cent of that element. Neither of these alloys showed the slightest traces of free carbon, chemically or microscopically, after 2075 hours (about three months) at 1650 degrees Fahr. (900 degrees Cent.).

The specimens were enclosed in a sealed quartz tube, together with an excess of graphite during the heat treatment, and the former increased in carbon to 5.27 per cent, while the latter decreased to 2.07 per cent. The original carbon was not recorded, but is believed from other similar experiments to have been about 3.5 per cent and 3 per cent, respectively. It is thus shown that silicon, by its absence, inhibits graphitization. This is not quantitatively consistent with the observation by the writer,[4] that equal increments of silicon, at least in the ordinary ranges, multiply graphitizing rate about equally.

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[1]Mgr. of Research, The National Malleable and Steel Castings Co., Cleveland, Ohio.

[2]Chemist, The National Malleable and Steel Castings Co., Cleveland, Ohio.

[3]"Effect of Silicon on Equilibrium Diagram of System Carbon-Iron Near Eutectoid Points," Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. LXIX, 1923, p. 791.

[4]"Graphitization at Constant Temperature," American Society for Steel Treating, Cleveland Convention, 1925.

It must be that there is a silicon minimum below which this rule fails. So far it has been impossible to advance any hypothesis accounting for this fact. The result may be ascribed by some metallurgists to the small, though distinct amount of chromium present instead of to the absence of silicon. This is not the writer's view, however, for much commercial malleable containing as much chromium is annealed regularly without occasioning any noticeable difficulty. The effect of chromium in preventing anneal will be referred to more in detail later.

Data recording the complete graphitization of very low silicon hypereutectic alloys have been frequently recorded,[5] and occasionally other observers have recorded the process even in hypoeutectic alloys.

It is of common knowledge, also, that the presence of sulphur or manganese in abnormal amounts will greatly retard or prevent anneal in the malleable industry.

The senior author has known for some eighteen years that chromium when present in moderate amount, would retard, or even practically prevent annealing. The matter was brought into prominence about 1922 by Enrique Touceda in connection with his work for the American Malleable Castings association.

There have also been frequent, though perhaps vague suggestions, that annealing difficulties might be occasioned by the unsuspected presence of various elements not usually determined in the course of commercial analyses. It was deemed worth while to begin an investigation of all the available elements to determine what their effects on graphitization might be in order to determine which, if any, must be guarded against if annealing was to go on without interference.

To Deal Only with Elements Which Are Harmful

While our investigation covered a much wider field, the present paper will deal only with those elements which are harmful when present in iron of normal composition with respect to the elements silicon, manganese, phosphorus, sulphur, and carbon, and will also ignore the presence of elements not forming intermetallic compounds, but present as oxides, silicates, etc.

[5] Cf. Ruer and Iljin, "Metallurgie," VIII—97.

Up to uranium, there are ninety-two possible elements of which a few have not yet been discovered. Certain of these may be excluded from consideration on *a priori* grounds. Thus, the six elements, iron, silicon, manganese, phosphorus, sulphur, and carbon, are by hypothesis, present in normal amounts. The halogens, fluorine, chlorine, bromine, and iodine, form salts of iron, and not intermetallic compounds.

Alkalies

It is believed that neither the alkalies, potassium, sodium, rubidium, caesium, and lithium, nor the alkali earths, barium, strontium, calcium, and magnesium, can be retained as intermetallic compounds in molten iron. The evidence in favor of this assumption is that although potassium, sodium, calcium, and magnesium are always present in blast furnace refractories, and slags, and barium is occasionally a constituent of iron ores, none of these elements could be found in commercial pig iron. Attempts to alloy lithium, calcium, and magnesium with molten cast iron repeatedly failed, although these elements hold out a greater chance of success than do the other members of their groups. Mercury, also, would volatilize from molten iron.

Gases

The noble or rare gases, argon, helium, krypton, neon, and xenon, were omitted because of their rarity, and because no chemical means for their determination exist. We have cause to suspect, however, that argon at least, is like nitrogen, capable of solution in solid iron. None of the five noble gases form any chemical compounds, hence, if present in iron, can only be there in solution.

The work of Sawyer,[6] and of Bean, Highriter, and Davenport,[7] was deemed sufficient to exclude nitrogen from consideration.

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[6]"Nitrogen in Steel," Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. LXIX, 1923, p. 798.

[7]Bean, Highriter and Davenport: "Fractures and Microstructures of American Malleable Cast Iron," Transactions of the American Foundrymen's Association, Vol. XXIX, p. 306.

Hydrogen was omitted, for we found no means of introducing it in quantity into iron melted in the air. Traces are always present.

Oxygen we found impossible of investigation for several reasons. It escapes very readily from cast iron during freezing.

Jordan of the Bureau of Standards[8] finds but small amounts of this element in any normal white cast iron.[9] Its determination presents such difficulties that except by the vacuum fusion method, the results are of but little interest or value.

Additional Elements Considered

Certain elements were not available to us on account of their rarity, but the following were secured, and attempts made to alloy them with iron:

Aluminum	Al	Neodymium*	Nd
Antimony	Sb	Nickel	Ni
Arsenic	As	Palladium	Pd
Bismuth	Bi	Platinum	Pt
Boron	B	Praseodymium*	Pr
Cadmium	Cd	Selenium	Se
Cerium*	Ce	Silver	Ag
Chromium	Cr	Tantalum**	Ta
Cobalt	Co	Tellurium	Te
Columbium†	Cb	Thallium	Tl
Copper	Cu	Thorium	Th
Gallium	Ga	Tin	Sn
Glucinum	Gl	Tungsten	W
Gold	Au	Uranium	U
Lanthanum*	La	Vanadium	V
Lead	Pb	Zinc	Zn
Molybdenum	Mo	Zirconium	Zr

This makes a total of thirty-four in addition to those previously considered.

[8] "Gases in Metals," Proceedings of the American Society for Testing Materials, Vol. 23, 1923, Part II, p. 7.

[9] Cf. "Gases in Malleable Cast Iron," Iron Age, Sept. 20, 1923, p. 764.

*Alloyed with Lanthanum, Neodymium, and Praseodymium.

**Alloyed with Columbium.

†Alloyed with Tantalum.

Experimental Procedure

The experimental procedure consisted of adding usually ½ to 1 per cent of the elements to molten white cast iron in a crucible in an electric furnace, and observing whether the resulting product could be annealed along with the normal works' product. The results of anneal were judged by microscopic investigation and by fracture. In some cases the concentration of the added element was increased considerably above ½ per cent or 1 per cent, where its possible presence in commercial melting stock was suspected or known. Also, in a few cases, the effect of small concentrations was studied. It is believed that a stufficient range of concentration was observed to cover any possible manufacturing condition.

Some Observations

Not all the elements mentioned can be successfully alloyed with iron, and of the entire series, only the following showed any detectable deleterious effect on commercial graphitization:

Antimony	Sb	Molybdenum	Mo
Boron	B	Selenium	Se
Cerium*	Ce	Tellurium	Te
Chromium	Cr	Tin	Sn

It is possible that more accurate quantitative methods of experiment[10] might add to this list some elements which have a very slight effect.

The effect of molybdenum was very slight, and became noticeable only when several per cent were present.

The accidental presence of antimony, boron, cerium et al., selenium, molybdenum and tellurium has not so far been observed in commercial white cast iron. Be it remembered that the effect of oxygen, if by chance it can be present in quantity in otherwise normal iron, has not been included in our investigation. Through the kindness of the Bureau of Standards we have learned that

*Including Lanthanum, Neodymium and Praseodymium.

[10]H. A. Schwartz, "Graphitization at Constant Temperature," Cleveland Meeting of American Society for Steel Treating, Sep. 14, 1925.

a badly scorched heat, from which the manganese was completely, and the silicon largely eliminated, and to which additions were then made, bringing these elements back to normal, may contain much oxygen after freezing. It is not of record that this heat annealed in any abnormal manner.

Further, we have frequently made experimental white cast iron laboratory heats from washed metal, ferro-manganese, and ferro-silicon, which gave no difficulty in graphitization. These facts lead us to doubt whether the presence of oxygen can inhibit annealing,[11] although in the absence of formal experiment we can make no positive assertion on the subject. We can say definitely, however, that any conclusions based on oxygen determinations on crushed samples, by the Ledebur method are valueless.

Some observers feel that chromium is harmful to a noticeable degree when present in the smallest traces. Speaking on qualitative evidence only, the writers would not expect a commercially noticeable effect below .02 per cent of that element, and indeed, would feel that at .05 to .07 per cent only an extremely slight retardation of annealing might be noticed. Towards .10 per cent the matter would grow serious while at .25 per cent the process would probably become commercially inoperative.

Quantitatively, the effect of tin is approximately equal to that of chromium in the lower concentrations.

A partially successful attempt was made to correlate the inhibiting action of the harmful elements with any effect they may have on rate of carbon diffusion. Our results in this direction, though encouraging, are as yet not sufficiently complete to warrant detailed description in this paper. Approaching the problem from this viewpoint, we were able to devise a technique which on a laboratory scale at least, was uniformly successful in overcoming the deleterious effects of many of these elements.

The action of chromium, unfortunately the most important of the series, has not yet been satisfactorily explained from this viewpoint. The mechanism by which it stabilizes cementite remains unknown. That it is capable of some form of metal-

[11] "On the Graphitization of Iron-Carbon Alloys," Kotaro Honda and Takejiro Murakami, "The Journal of the Iron and Steel Institute," 1920, No. II; Vol. CII, p. 287.

lurgical control seems indicated by the wide variance of opinion as to the quantities which cause harm. To the author this suggests that the quantitative effect of a given concentration of this element can be varied by some metallurgical condition so obscure as to have escaped the attention of those, including ourselves, who have studied the problem.

If this be true, then there is at least a hope that this unknown variable may be discovered and perhaps brought under such control as to make possible the minimizing of the chromium effect.

The reader is reminded that this paper deals only with the elements which are harmful as inhibiting graphitization. It is not to be concluded that the remainder may be added *ad libitum*, to malleable castings. Many of them are objectionable for other reasons, even though they do not interfere with annealing.

Conclusions

It has been shown that of the ninety-two possible elements, only antimony, boron, chromium, cerium, lanthanum (and rare earths), selenium, tellurium, and tin, interfere with graphitization when present in small amount, in iron of normal composition. Of these, only chromium and tin have been detected in commercial materials, so far.

The role of oxygen in this connection is not yet demonstrated, although no evidence yet exists that it inhibits graphitization.

It is clearly known to the authors that this paper does not exhaust all the factors influencing graphitizing rate.

The Effects of Some Modifications of a Rapid Annealing Method on the Physical Properties of Malleable Iron

By Anson Hayes,* E. Lee Henderson* and G. R. Bessmer,*
Ames, Iowa

Previous work done by other investigators as well as that done in this laboratory, in attempts to produce completely malleablized cast iron in short annealing periods, has resulted in a prod uct which is somewhat inferior to the best material produced by the present commercial methods of annealing. Usually the ductility has been two or three per cent less and the tensile strength two to four thousand pounds less than the commercial product where complete graphitization was brought about by the rapid annealing method.

This paper is a preliminary report of a careful study that is being made of the influences of modifications of various rapid methods of annealing upon the physical properties of the product.

Although in recent years, through the influence of the American Malleable Castings Association, a very great improvement has been made in the properties of malleable iron, the authors feel that there is nothing in the inherent nature of the rapid method used in the larger portion of the work at Iowa State College that would prevent a complete duplication of the best properties produced by the present industrial method. In certain respects it would seem that properties superior to those produced by the present methods might be expected.

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*Iowa State College.

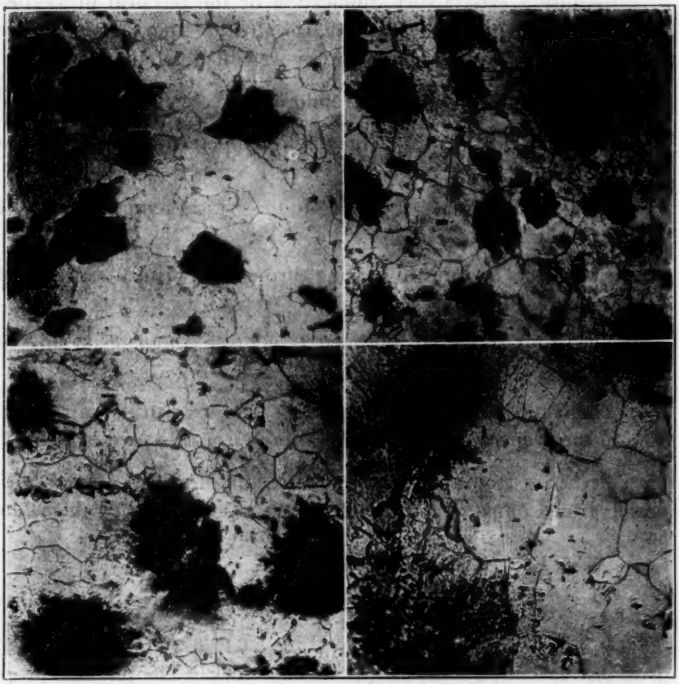

FIG. 1—(UPPER LEFT) INITIAL HIGH TEMPERATURE PRODUCED VARIABLE GRAIN SIZE AND LOWERED THE TENSILE STRENGTH—X 120—AVERAGE TENSILE STRENGTH = 49,000. AVERAGE DUCTILITY = 21 PER CENT

FIG. 2—(UPPER RIGHT) PRELIMINARY TREATMENT AT A LOWER TEMPERATURE PRODUCED A FINER GRAIN STRUCTURE WHICH DUPLICATED TENSILE STRENGTH AND GAVE DUCTILITY WITHIN TWO PER CENT OF THE COMMERCIAL ANNEAL—X 120—AVERAGE TENSILE STRENGTH = 51,800. AVERAGE DUCTILITY = 20 PER CENT

FIG. 3—(LOWER LEFT) PRESENCE OF FRAGMENTS OF FREE IRON CARBIDE REDUCED THE DUCTILITY SLIGHTLY—X 120—AVERAGE TENSILE STRENGTH = 50,100. AVERAGE DUCTILITY = 19 PER CENT

FIG. 4—(LOWER RIGHT) LONG PERIOD AT HIGH TEMPERATURE PRODUCED VERY COARSE GRAIN STRUCTURE, LOWERING TENSILE STRENGTH AND DUCTILITY—X 95—TENSILE STRENGTH = 48,800 (AVERAGE). AVERAGE DUCTILITY = 19 PER CENT

Because a satisfactory duplication of the physical properties of some excellent malleable iron has already been obtained it is hoped that this brief preliminary report will be of interest.

This study was centered around an investigation of:

1. Effects of time at the high temperature (949 degrees Cent.)

2. Effects of rates of cooling to the critical temperature (771 degrees Cent.)

3. Effects of rates of cooling through the critical range (771 to 677 degrees Cent.)

The study as herein outlined is not yet complete on any of these phases.

The composition of the white cast iron used in this investigation in the preparation of the malleablized iron is shown in Table 1.

Test bars from the same heat were annealed by the Iowa Malleable Iron Company at Fairfield, Iowa, who furnished the white

Table 1

Silicon Per cent	Sulphur Per cent	Phosphorous Per cent	Manganese Per cent	Total Carbon Per cent
0.94	0.032	0.151	0.26	2.23

iron test bars used in this experimental work. The physical properties of these commercially annealed bars are included in Table 2 for reference.

Those bars which were annealed by the commercial method and which show the highest ductility were packed in a mixture of fifty per cent rolling mill scale and fifty per cent crushed furnace slag. They show a considerable thickness of decarbonized material on the surface of the bars. The commercially annealed bars showing the lower ductility were packed in crushed furnace slag and show almost no decarbonization on the surface.

The reader is referred to Table 2 for statements of the various treatments made and of the physical properties resulting. In this experimental work the test bars were graphite packed in wrought iron pipes 12 x 2 inches, before placing in the furnace.

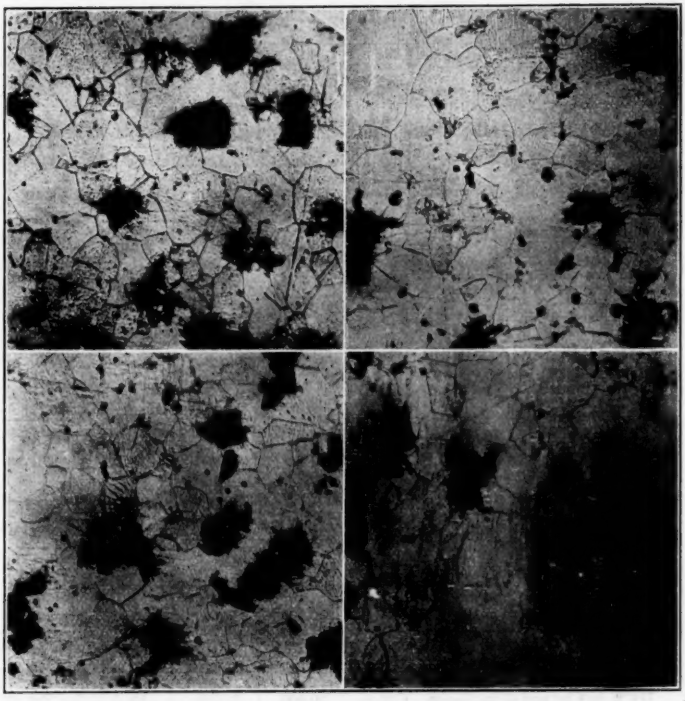

FIG. 5—(UPPER LEFT) A SLOWER RATE OF COOLING TO THE CRITICAL RANGE THAN WAS USED UNDER (3) ALLOWED MORE COMPLETE ABSORPTION OF FREE IRON CARBIDE—X 120—AVERAGE TENSILE STRENGTH = 50,800. AVERAGE DUCTILITY = 22 PER CENT

FIG. 6—(UPPER RIGHT) NO FURTHER BENEFIT RESULTED WITH A STILL LOWER RATE OF COOLING TO THE CRITICAL RANGE THAN WAS USED UNDER (5)—X 120—AVERAGE TENSILE STRENGTH = 50,000. AVERAGE DUCTILITY = 21 PER CENT

FIG. 7—(LOWER LEFT) TOO SHORT A TIME AT THE HIGH TEMPERATURE LEAVES FRAGMENTS OF FREE IRON CARBIDE AND SOME PEARLITE. THE DUCTILITY IS REDUCED—X 120—AVERAGE TENSILE STRENGTH = 50,700. AVERAGE DUCTILITY = 17 PER CENT

FIG. 8—(LOWER RIGHT) PRELIMINARY ANNEALING TREATMENT AT A LOWER TEMPERATURE (878°C) AGAIN RESULTED IN PHYSICAL PROPERTIES COMPARABLE TO THOSE OF THE COMMERCIAL ANNEAL BY THE NON-OXIDIZING PACK —X 120—AVERAGE TENSILE STRENGTH = 50,300. AVERAGE DUCTILITY = 22 PER CENT

Table 2

METHOD OF TREATMENT	Overall Time	Tensile Strength	Yieldpoint by Dividers	Elongation in 2 Inches	Structure
	Hour	Pounds Per Square Inch	Pounds Per Square Inch	Per Cent	Figure
(1) 1 hr. at 982°C., 4 hr. at 927°C., cooled to 777°C. in 2 hr. and 40 m.; cooled from 777°C. to 672°C. in 18 hr.; cooling rate through critical range, 5.8°C. per hour..	29.5	49,000 48,300 49,600	32,700 32,000 33,300	18.5 21.0 22.5	See Fig. 1.
(2) 4 hr. and 35 m. at 871°C., heated to 927°C. in 25 m., 5 hr. at 927°C.; cooled to 782°C. in 1 hr. and 45 m.; cooled from 782°C. to 674°C. in 18 hr.; cooling rate through critical range, 6°C. per hr.....	33.0	51,400 51,400 52,500	33,300 33,200 33,200	18.5 20.0 21.5	See Fig. 2.
(3) 5 hr. at 927°C.; cooled to 777°C. in 1 hr. and 45 m.; cooled from 777°C. to 668°C. in 19 hr.; cooling rate through critical range, 5.7° per hr.....	29.0	50,000 49,700 50,600	32,500 33,000 31,700	18.0 19.0 20.0	See Fig. 3.
(4) 9 hr. at 949°C.; cooled to 779°C. in 2 hr. and 50 m.; cooled from 779°C. to 671°C. in 17.5 hr.; cooling rate through critical range, 6.2°C. per hr.....	32.5	48,800 48,800	30,900 30,900	18.0 20.5	See Fig. 4.
(5) 4 hr. at 949°C.; cooled to 774°C. in 2 hr. and 45 m., cooled from 774°C. to 674°C. in 22.75 hr.; cooling rate through critical range, 4.4°C. per hr.....	33.0	50,600 51,000	33,600 33,700	21.0 22.5	See Fig. 5.
(6) 4.25 hr. at 949°C.; cooled to 774°C. in 4 hr. and 45 m.; cooled from 774°C. to 663°C. in 24 hr. and 15 m.; cooling rate through critical range, 4.6°C. per hr....	32.0	50,600 49,400	32,300 34,200	19.0 22.5	See Fig. 6.
(7) 2 hr. at 949°C.; cooled to 774°C. in 5 hr.; cooled from 774°C. to 668°C. in 23 hr.; cooling rate through critical range, 4.6°C. per hr.....	31.7	51,600 49,700	33,600 33,400	17.0 18.0	See Fig. 7.
(8) 4 hr. at 878°C.; heated to 935°C. in 25 m.; 5 hr. at 935°C.; cooled from 935°C. to 779°C. in 2 hr. and 40 m.; cooled from 779°C. to 674°C. in 27 hr.; cooling rate through critical range, 4°C. per hr.....	41.0	50,400 50,300	32,700 32,200	22.0 21.5	See Fig. 8.
Commercially annealed in Neutral Pack.....		51,900 51,300 52,100	33,900 35,300 34,000	23.0 21.5 20.5	See Fig. 9.
Commercially annealed in Oxidizing Pack.....		50,400 50,800	32,800 33,800	23.5 25.0	Not shown

Legends accompanying the photomicrographs are quite complete and no further description of treatment or structure will be made.

Summary and Discussion

From the results shown in Table 2 and by the accompanying figures the conclusion is drawn that any annealing method which

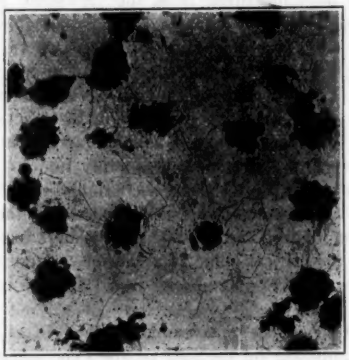

FIG. 9—FINE GRAIN STRUCTURE AND SMALL TEMPER CARBON SPOTS GIVE VERY GOOD PHYSICAL PROPERTIES—X 120—AVERAGE TENSILE STRENGTH = 51,800. AVERAGE DUCTILITY = 22 PER CENT

produces small grain structure and well rounded carbon spots, and which results in complete graphitization, will duplicate the physical properties of the malleable iron produced by the present commercial methods.

Such properties can be duplicated in annealing periods of forty hours or less.

The failure to duplicate the slightly higher ductility of the commercially annealed product from the oxidizing pack is very probably due to the reduction in the amount of temper carbon produced by such a pack.

DISCUSSION

CHAIRMAN E. TOUCEDA: Mr. Hayes, there has been a great deal of work done in this connection. I feel the various experiments you have tried, have been tried many times. I believe what you state is absolutely so and I think we can have a valuable discussion here if the members will dwell on certain things—what is going to happen to your castings when you get them to 1810 degrees? You see, all these practical points prevent a practical application of the quick anneal you refer to. We haven't any doubt that these things happen.

Another thing I would like the members to dwell on in the discussion is this: This has been measured from the viewpoint of tensile strength in structure, whereas there are other factors in malleable lines, the impact test, for instance. We find a good many cases where a bar will stand good tensile strength and it isn't worth anything in the impact.

F. L. WOLF: I would like to say we have done a lot of work on quick anneal. In fact, we have had a lot of practical difficulties in handling volume. We have annealed as high as a ton and the material was quite compact. The entire cycle was ninty hours. We tried it with packing and without and found there seemed to be no change so far as physical properties were concerned. We carried out the impact test and found no difference. There seemed to be no change except we found we had to go through the critical point at a rate of 5 degrees Fahr. per hour. In handling a ton, we had to move pretty fast. We ran up to 1700 degrees, that was our maximum.

A. HAYES: That is the maximum we used in all of these. That higher point was a mistake on the part of the experimenters. They didn't intend to get it that high but they did. Our idea is that ultimately, if the thing ever should turn out to be feasible we wouldn't use packing. I want to call attention to a little report we presented at the sectional meeting of the Society for Steel Treating at Moline a couple of years ago, in which we reported the shock test and tensile properties and in those cases the shock test was all right but in a particular heat our tensile properties and elongations were poor.

L. J. KELLY: We experimented with a muffle furnace to see if we could anneal a run of castings. The cooling time was less than five degrees Fahr. per hour. All the castings of the smaller sections were perfectly annealed but the heavier castings runnings around half and three-quarters of an inch were not so good. Lighter castings were all we could test for.

F. L. WOLF: Our best results on the anneal, packing the thermo-couple, showed big lag all through and we had all kinds of iron come out.

CHAIRMAN TOUCEDA: I think we have tried this in every way it can be tried almost, in the past ten or twelve years. The only trouble we have had was the laboratory experiments do not indicate what you can do with it commercially. It is the difficulty of being able to do your proposition commercially, with fifty or sixty tons in your oven.

A. HAYES: In order to dispel as much as possible the idea that I am a bolshevist in the annealing business, I want to simply make these remarks: The program of research as we have taken it up on these attempts at studying the possibilities of shortening the cycle is as follows:

First, to work out the mechanism of graphitization and find out what that is. That we feel we have done.

Second, to determine in the laboratory the minimum time that can be used to complete graphitization.

Third, to find out all of the causes of variation in rates of graphitization of white irons now considered good commercial material.

Fourth, to find out, as far as possible, methods of avoiding those variations.

Fifth, in light of those variations and methods of correcting them, to approach the ideal as nearly as possible, maintaining a suitable factor of safety for production.

We are not advocating general attempts at quick annealing on anything of the kind. We are attempting to get together enough scientific information on this problem so when it is attempted a suitable factor of safety can be adopted and great loss, due to under-annealing, may be avoided. We have only completed half of it so far. We are not even advocating production experiments at the present time.

MR. MORROW: I would like to ask Mr. Hayes or the chairman if they had any trouble with decarburization of the castings and poor machine quality on tapping and drilling work.

A. HAYES: There hasn't been very much machining done. We machined out the shock test samples and in other experimental work we have done, we have found occasion to machine out cylinders in order to analyze various layers of the bar as we go in.

In such machining operations as we have had occasion to carry out, we have found no difficulty. Difficulty is certainly to be expected if there are any considerable quantities of fragments of massive iron carbide left. The great majority of experiments we have tried out have been carried out by packing the material in graphite.

MR. SPENCER: In employing this rapid rate of cooling, I wonder whether Mr. Hayes has considered iron of various compositions. There are times when furnaces don't function properly and you have a heat abnormally oxidized when it is necessary to add both silicon and manganese. Have you found iron of that composition more sensitive?

A. HAYES: The fact is that we have only been able to work on comparatively small number of irons. Altogether we have not worked on more than some fifteen and on the scale we are doing experimental work, four or five hundred bars will last us for a year. Out of those samples we work with we have only struck one sample, which I mentioned in the first paper, which was very slow annealing.

Report of Committee on Specifications for Malleable Cast Iron

To the Members of The American Foundrymen's Association:

A joint meeting of A. S. T. M. Committee A-7 and your A. F. A. Committee was called by Chairman W. P. Putnam of Committee A-7 for May 6th last at the Statler Hotel, Buffalo, there being present a good attendance of both committees.

It was decided by a majority vote that a yield point of 30,000 pounds per square inch, to be determined by the drop of the beam, be added to the tensile requirements. This action was deemed advisable by reason of the fact that engineer designers were unable to gather from the specification as it stood what yield point they were warranted in using in their calculations. At this meeting a committee of three was appointed to report on the advisability of drawing up specifications covering different grades of malleable iron.

At the A. S. T. M. annual meeting it was voted that the tentative specification be revised to include a yield point, by drop of beam, of 30,000 pounds per square inch.

The A. F. A. Committee, therefore, recommends to the A. F. A. Board of Directors for approval their endorsement of the revision of the A. S. T. M. tentative specification for malleable iron as to yield point requirement.

Respectfully submitted,

W. R. BEAN,
R. A. NOURSE,
E. A. WHITE,
L. S. MURPHY,
H. BORNSTEIN,
E. TOUCEDA,
Chairman,
Committee on Specifications for Malleable Iron Castings.

Carbon Steel and Carbon Vanadium Steel by the Converter Process

By S. R. Robinson,* Bay City, Michigan

Steel made by the converter process has become very scarce in this country in recent years, having been displaced by electric steel both acid and basic in a great many places.

The Industrial Works, Bay City, Michigan, maintain a foundry for the production of the castings entering into their product, locomotive cranes. As this company is one of a very few still using the converter process in the production of steel for their steel castings, it is hoped that an account of the practice pursued will be of interest to the members of this association.

Cast Carbon Steel Practice

It has been claimed that electric steel is superior to converter steel due to fewer oxides and non-metallic inclusions in electric steel. If the superiority of electric steel is due to this it would seem that tests on "as cast" un-annealed converter steel would show low results on elongation and reduction of area on tensile tests.

In this connection the writer desires to call attention to results obtained in regular practice on "as cast" un-annealed test bars poured with carbon converter steel.

The Industrial Works specification on un-annealed cast carbon steel calls for the following minimum physical properties:

Tensile Strength	60000 lbs. per sq. in.
Yield Point	30000 lbs. per sq. in.
Elongation in 2 inches	15 per cent
Reduction of Area	18 per cent

*Metallurgist, Industrial Works.

Test Results

A separate test bar is poured from every other blow of steel and the average physical properties obtained on all test bars poured and tested in the "as cast" condition in April and May, 1925, are as given in Table 1.

Melting and Refining Equipment

We use a 60-inch diameter cupola inside the lining. The charge consists of 70 per cent steel scrap and 30 per cent low phosphorous pig iron which is melted with 320 pounds of coke to the ton of metal charged. We blow in a 3-ton side blow converter.

Table 1

AVERAGE PHYSICAL PROPERTIES FOR TEST BARS "AS CAST" APRIL AND MAY, 1925

	April	May
Tensile strength, lbs. per sq. in.	70000	69250
Yield point, lbs. per sq. in.	39000	39200
Elongation per cent in 2 inches	19.5	22.5
Reduction of area per cent	24.5	27.3
Number of blows	77	105

HIGHEST PHYSICAL PROPERTIES FOR TEST BARS "AS CAST" APRIL AND MAY, 1925

	April	May
Tensile strength, lbs. per sq. in.	79600	77500
Yield point, lbs. per sq. in.	45850	42750
Elongation per cent in 2 inches	20.0	25.0
Reduction of area per cent	24.1	34.1
Chemical Analysis:		
Carbon	.18	.21
Manganese	1.11	.88
Phos. and Sulphur	under .05	under .05

Only one blow in April went as low as 15 per cent elongation.
Only one blow in May went as low as 17 per cent elongation.
Total metal charged in April 490000 lbs.
Total metal charged in May 713000 lbs.

Sulphur

For the removal of sulphur the cupola metal is treated in the ladle with alkali compound. By the use of 35 pounds of granular soda ash to a 3 ton blow the sulphur is kept below .07 per cent. On particular work where a lower sulphur is desired we use 50 pounds of an alkali compound containing sodium carbonate and sodium hydroxide. By this practice the sulphur is kept below .05 per cent.

We are all familiar with the controversy over high sulphur in converter steel in the past. On one side were the shop men

who claimed that high sulphur was harmful, and on the other side were the chemists and metallurgists who claimed that good steel castings could be made with high sulphur metal. This latter view was based to a great extent on the results of physical tests made on annealed test coupons. The writer being in this last group admits that he held to this latter view, with limitations, up until the introduction of the alkali compound. Since using this material and noting its beneficial effect on the castings themselves, the freedom from cracking being the main benefit, and leaving out any reference to the physical properties on test coupons, the writer is now convinced that it is necessary to have low sulphur to make good steel castings. We are convinced that this element in amounts above .05 per cent does have a harmful effect and if it can be kept down to .03 per cent the steel will be still better.

Phosphorus

The phosphorus is kept below .05 per cent at all times.

Ferro-Alloys

Twenty-six pounds of 80 per cent ferro-manganese to the ton of steel poured is used, adding it to the converter. Twelve pounds of 50 per cent ferro-silicon per ton of steel poured is used adding it to the ladle.

Losses

Losses are estimated as follows: Cupola loss, three per cent; converter loss, fifteen per cent.

Cost

The cost of molten metal in April and May, 1925, was less than 1.75 cents per pound.

Chemical Analysis

The chemical analysis on cast carbon steel is kept within the following limits: Carbon, .17 to .22 per cent; Manganese .75 to 1.00 per cent; Silicon .30 to .40 per cent; Phosphorus under .05 per cent; Sulphur always under .07 per cent and under .05 per cent when desired.

Manganese

We keep the manganese high, that is, above .75 per cent and the carbon low. We get the tensile strength with the manganese and not with the carbon. In working to a physical specification on "as cast," un-annealed cast steel it is possible to obtain the tensile strength with carbon at .25 per cent and manganese at .60 per cent, but it is much more difficult to obtain the elongation with this composition than with the low carbon and the high manganese. We have also experienced much more trouble with cracking, using higher carbon and low manganese than we have with the low carbon and high manganese. An intensive study of the effect of high manganese on low carbon cast steel would be a very profitable field of investigation for the members of this association.

Our foundry organization relies on manganese to a marked extent. Just recently on a difficult casting the manganese was run up to 1.25 per cent with carbon .21 per cent with a perfect casting as a result. The physical properties of this steel "as cast" were as follows:

Tensile Strength	82950 lbs. per sq. in.
Yield Point	46950 lbs. per sq. in.
Elongation in 2 inches	20.5 per cent
Reduction of Area	34.1 per cent

Aluminum

Very little aluminum is used at any time. Aluminum is fatal to the elongation on steel tested in the "as cast" or un-annealed condition. No other deoxidisers of any kind are used.

Demanding Good Properties

Demanding good physical properties of cast steel in the "as cast" condition, and by that is meant good elongation and reduction of area as well as moderately high tensile strength, brings out two main points; namely, it assures the steel maker that his steel is free from non-metallic inclusions, and slag. He does not have to depend on annealing to cover up any defects but rather

he can carry on his heat treatment so that he will know for a certainty that his various treatments will give him the desired results. Further, steel which has good "as cast" properties behaves differently in the mold—it has less tendency to crack and the piping is not so great.

Heat Treatment

The regular annealing treatment given carbon steel is as follows:

Heat Treatment F: Heat to 1600 degrees Fahr. and hold at this temperature 1 hour per inch of section. Cool in furnace to 1350 degrees Fahr. Remove from furnace and cool in air.

A much more severe heat treatment for such castings as cast tooth gears for extra heavy duty is as follows:

Heat Treatment R: Heat to 1600 degrees Fahr. and hold at this temperature 1 hour per inch of section. Quench in water and remove before cold. Reheat to 950 degrees Fahr. for 1½ hours. Cool in furnace.

Table 2

COMPARISON OF PROPERTIES OBTAINED WITH HEAT TREATMENTS F AND R

	As Cast	Heat Treatment F	Heat Treatment R
Tensile strength, lbs. per sq. in...	68800	72000	85000
Yield point, lbs. per sq. in.....	38600	42000	50000
Elongation in 2 inch.....	19.0 per cent	31.0 per cent	18.0 per cent
Reduction of area.....	24.0 per cent	46.0 per cent	40.0 per cent

The above heat treatments will give the physical properties to attached test specimens as shown in Table 2.

Carbon Vanadium Steel Practice

The cupola charge for vanadium steel consists of 50 per cent low phosphorus pig iron and 50 per cent purchased low phosphorus steel scrap. All vanadium steel is treated with alkali compound using 50 pounds to the three ton blow, as explained under carbon steel. The ferro-manganese is added in the converter and the ferro-vanadium and ferro-silicon in the ladle.

The chemical analysis is kept within the following limits: Carbon .35 to .40 per cent; manganese 1.00 to 1.10 per cent:

phosphorus and sulphur below .05 per cent; silicon .30 to .40 per cent; vanadium .18 per cent.

All vanadium steel is heat treated as follows:

Regular vanadium heat treatment: Heat at the rate of 400 degrees an hour to 1650 degrees Fahr. and hold at this temperature 1 hour per inch of section. Remove charge from furnace and cool in air until black.

Reheat to 1200 degrees Fahr. and hold at this temperature 1 hour per inch of section. Cool in furnace.

Special vanadium heat treatment: Heat at the rate of 400 degrees Fahr. an hour to 1650 degrees Fahr. and hold at this temperature 1 hour per inch of section. Remove charge from furnace and quench in oil. Remove from oil before cold.

Reheat to 950 degrees Fahr. and hold at this temperature 1 hour per inch of section. Cool in furnace.

The above heat treatments will give the following physical properties to attached test specimens as shown in Table 3.

Table 3

COMPARISON OF PROPERTIES OBTAINED WITH REGULAR AND SPECIAL VANADIUM STEEL HEAT TREATMENTS

	Regular Vanadium Heat Treatment	Special Vanadium Heat Treatment
Tensile strength, lbs. per sq. in.....	96000	125000
Yield point, lbs. per sq. in.....	65000	90000
Elongation in 2 inches.....	22 per cent	18 per cent
Reduction of area.....	45 per cent	35 per cent

Skim Gates

The foundry produces a large number of jack beams or out-riggers for wrecking cranes which are poured with carbon vanadium steel. Up until approximately one year ago the practice in regard to the heat treatment of these castings was to give them the first part of the treatment which consists of an air quench from 1650 degrees Fahr. After this they were sent to the machine shop and rough machined on the top and bottom surfaces. If any welding was necessary it was done at this time. They were then returned to the foundry and given the second part of

the heat treatment, which consists of a draw at 1200 degrees Fahr. with furnace cooling. They were then returned to the machine shop for final machining. It frequently happened that these castings required welding on account of dirt and slag on the cope surface. As this welding, re-handling and re-machining was quite expensive, the foundry organization set to work to make them with a clean cope surface. If they could be made free from dirt and slag they could be given the full heat treatment in the foundry at one time and then finished machined with one set up on the planer in the machine shop. These castings are quite heavy for a converter shop, weighing up to 3400 pounds and having a cope surface of 12 inches by 120 inches or 1440 square inches.

All our converter steel is poured over the lip using a tea-pot ladle. Even with the utmost care some slag will enter the mold when pouring over the lip and a way was found to prevent this slag from entering the mold. We have all heard of skim gates for cast iron but to my knowledge no successful skim gate for steel has been used in regular practice up until the introduction of the device which I will endeavor to describe. This device was originated by J. H. Crawley, our foundry superintendent. The device consists of a basin made in a core with small holes through which the metal flows into a second basin and the metal then rises to a central opening from which it flows into the regular gate of the mold. This device will positively prevent the passage of any slag or dirt from the ladle into the mold. This device was described in a recent issue of THE FOUNDRY. It has been used with much success on all jack beam molds for the past year. When using it the jack beams are given the full heat treatment before leaving the foundry and are finished machined without any welding. This skim gate is used in regular practice in the foundry on any important work in iron, brass and steel and it is very successful.

DISCUSSION

CHAIRMAN J. H. HALL: This is a very interesting paper, gentlemen, especially as it holds up the converter as opposed to the electric furnace. We have heard so much in the last ten years about how good electric steel can be, that it is very welcome to hear how good converter steel can be. I feel sure that in this audience there are those who will wish to contribute to this discussion.

R. H. WEST: I would like to ask Mr. Robinson whether he advocates the use of steel castings unannealed by the converter process or whether it is just adapted to this special work, and whether he has found this method successful in his own practice?

S. R. ROBINSON: We do not advocate using steel castings unannealed in any important work. It is true we do use a few on unimportant places unannealed. The main object was to keep the foundry organization on their toes. In adopting this specification for them to work to, we felt that if they made good steel with good physical properties in the "as cast" condition, we at least would know that they had good metal to start with, that is, that it should have moderately high tensile strength and good elongation and reduction of area.

CHAIRMAN HALL: You touched there, Mr. West, on what is rather a hobby of my own. I should like to ask you what is your opinion of the use of unannealed cast steel?

R. H. WEST: I would like to answer that in another way, in putting the question this way; has Mr. Robinson examined any castings unannealed for strains? Take, for example, the casting that has been put into the machine shop and machined. Notice the difference in the machining measurements, in the way of holding down to certain sizes. Then take that casting and saw it up in order to determine the strain that is in the casting. How could he account for a good perfect casting in the unannealed shape?

S. R. ROBINSON: I am sorry to say that I have never made any such test on castings in that way.

R. H. WEST: We have specialized on steel wheels and auto truck wheels. In the first of our experience it was a very difficult matter to produce steel wheels that would stand the strains of both hot and cold climates. Getting into the cold, frost-bitten climate, we found that we had trouble with our wheels checking and cracking due to the rough surface, but this was entirely eliminated by proper annealing. We found that most of our trouble was in the strain in the original casting as put out to the trade. Where we encountered a cracked casting we would run a hack-saw blade through it and find that it would open up twice the width of the blade or it would press in there so that we could not

get the blade out, showing that the initial strains were still in the casting and must be removed.

R. A. BULL: Emphasizing the point Mr. West has made, I would like to say that probably a dozen different times I have seen some interesting things happen to indicate the presence of those internal strains in castings of fairly large size. Castings that were more susceptible, due to design and to the bad effect of internal strain, if while being cleaned before they had been annealed or normalized received a slight shock during cleaning operations, broke in two with a very loud report. I saw one case in a casting about twenty-five feet long by ten feet wide. I was right alongside of it when it broke. It was lifted about two feet off the shipping trestle by a crane without receiving any kind of shock that could be considered a shock by observation. When about two feet from the top level of the horses it broke clear across with a loud report. I have never seen a casting like that, or any other kind, that suffered such a catastrophe after it had been heat treated.

I would like to say that it might be appropriate for those who represent the electric steel casting industry to concede the fact that the steels Mr. Robinson describes in his interesting paper and other converter steels are absolutely of very high grade. I think the longer we are in the steel casting business the more we realize that it is not the process that is used or the composition of the steel, either one or both, so much that makes a good steel casting as it is the right kind of foundry practice. If you do not have that, you cannot have the best steel in the world turned from the furnace and you will not get a good product. In this connection I am glad to see Mr. Robinson testify to the good effect of manganese. I have always had a great deal of respect for manganese. I figure it is perfectly silly for some producers to attempt to specify or limit the foundryman to anything like .80 manganese which has been done, and to go further than that in the effort to impose other limitations when, as I say the essential features of making good steel castings lies in the right kind of foundry practice. I believe it is fundamentally wrong for consumers to try to tie the hands of producers who ought to know more about the way to make steel than the fellow that uses it. If we do not, somebody ought to put us in some other kind of business.

MR. SEGAL: My opinion on converter steel, with which I have had some experience, runs in these lines; that the old Bessemer process at one time was a great process. Well, it happened that along came the open hearth process, and the railroads of this country threw out all the Bessemer rails that were being made in this country on account of high sulphur. Why did we throw them out? Because the open hearth process was a sure process of eliminating the sulphur, and by that they got a better edge.

In speaking of the electric furnace which I have handled, both converter and open hearth electric, I have made some of the most difficult

castings that have been made in the country, and I find that the electric furnace has given just as good results as the open hearth process. With the mixture of scrap that goes into the acid furnace of low cast and the low sulphur, you will have no trouble but take that same material, put it into a converter and with the utmost care it will pick up sulphur and you cannot get away from it. I have seen times when I have made tests with large castings; for instance, on bars which are used sometimes in the brickyard. I made six of them out of a converter; made six of them out of the open hearth, and made six of them out of an open hearth with coke. Now the ones I made out of the converter broke completely in two in four or five different places, with sulphur running around about five and a little above. Another experiment was made with coke in order to cut down our pig in our charge in the open hearth. We made a test on the bars and found the same results in breakage. I then got some charcoal and put it down in the bottom of this furnace, put the charge on top of it and cast the same bars and there was not a crack in them. That goes to show that with the same kind of scrap and material you are more sure on that kind of process than you would be by using the converter. You would not need to watch your process so closely, because once you put in your metal into the open hearth electric, you know what you are going to get out of it, but you do not know what you are going to get out of it when you put it in a converter.

R. A. Bull: I would like to say, in answer to the statement just made, that you do not know what you are going to get out of it because the thing won't go automatically; it has to be operated with a high degree of skill, and I say that from a great deal of experience and with a great deal of respect for the electric furnace; the process does not make the difference as does the practice employed, not only in making steel but in making molds and every other detail of foundry procedure.

S. R. Robinson: I do not know whether Mr. Segal realizes that we now have the sulphur under control. Take the sulphur as it comes out of the cupola—our cupola iron, the sulphur will run around .09 to .11, and by adding this sodium alkali compound you can get your sulphur right under control. I have the picture of a bend test we recently made on a piece of unannealed converted steel ¾ inch by 1 inch; the bar was bent flat on itself. That metal is not dead soft steel, it has a tensile strength of 76 thousand pounds, a yield point of 40,000, and in the "as cast" condition it stretched 28½ per cent, and a reduction of 43.4 per cent. The composition of it is .20 carbon, 1 per cent manganese, .045 phosphorous, .034 sulphur and .37 silica; so we have the sulphur under control.

Mr. Segal: I realize that the sulphur is under control, but do you always have the sulphur under control because there is bound to be a variation there. You take it in the electric furnace and take it in the

open hearth. Sometimes a man will pick up sulphur and say, "Where am I getting it from?" I do not condemn the converter process, but we all know down in our own heart that our best steel castings have been made through the open hearth and through the electric furnace process. It is along those lines I have been working, and I have largely given up the converter and have never made a study of it since that time. If there has been anything developed since that time, I am glad of it.

T. BURKE: What do you use as a charge in the cupola? Do you run straight steel scrap or do you use a mixture of steel scrap and pig iron?

S. R. ROBINSON: We use 70 per cent steel scrap and 30 per cent low phosphorous pig. We do not add any ferro silicon.

CHAIRMAN HALL: The Chair would like to ask in connection with this discussion of unannealed cast steel—we have heard about the strain remaining in it—if any one has any data on shock test or toughness of unannealed as compared to the annealed? We all know that to leave out the annealing leaves the initial strain in the metal. Has anyone any data on the toughness of unannealed cast steel?

D. D. REESE: I just want to tell you men that we have been doing some work similar to that which Mr. Robinson is doing. We are operating a 3,000 pound converter and have made about 4,500 heats in the converter in the last two years. We have been using this desulphurizer, a mixture of sodium carbonate and sodium hydroxide, 70 of carbonate to 30 of sodium hydroxide, and using a half per cent to one per cent of the weight of metal. In our cupola we are charging 90 per cent steel scrap and 10 per cent pig iron at present. In the past, sometimes, we have run our cupola on 100 per cent steel scrap.

Before we started using the desulphurizer, our sulphur was .09 or .10 or sometimes .11, and we noticed that our castings were cracking. After we started using the desulphurizer we eliminated cracks to a large extent. In the past two months we have also been running up our manganese. Our manganese now is running up to about 1 per cent, with .17 to .20 carbon. We have compared the tensile properties of our steel with the open hearth steel and with electric furnace steel. If we put the data down in tabulated form and conceal the process by which each is made, I doubt very much if you could tell just what process we used. As to the skill of the operator. Right now I have a foreigner operating my converter. I imagine he has been in this country about ten years; we pay him 68 cents an hour. We have very uniform practice in converter steel. Our chemical analyses of all these 4,500 heats check up very closely and the process is very uniform. I believe the steel makers have thrown out converter steel because of high sulphur in the past, but our practice now with the desulphurizer is very uniform.

We use a very simple method; the acid process in the converter, and we use the desulphurizer as a basic material. The idea might be prevalent that you may have a lot of trouble with your converter lining or your ladle lining, but we have very little trouble. Then you may think that you would have trouble with the reaction that might occur in the converter, but there is no marked effect on the lining. We add the desulphurizer to the ladle just before the iron is tapped out and it forms a very fluid slag on top of the ladle. Then we take a skimmer and skim it off, just as Mr. Robinson has been telling you. We have been doing exactly the same as he has been doing and our results have been exactly the same.

J. T. MacKenzie: After listening to this discussion on sulphur I wonder if those here are familiar with the work done in grey iron twenty or twenty-five years ago, by Mr. Cutler, on sulphur. He found a great deal of trouble from high sulphur in some grey iron castings. After studying the process he solved it in this way. By tilting the mold at the start of the pour so that there was no churning or agitation of the metal during pouring, he found that on castings that he had been losing from high sulphur he was able to get with a higher sulphur a very nice machinable iron.

It occurs to me that we can account for the difference in the metal from the converter as compared to that from the electric furnace by the percentage of oxides. In the converter you have the oxide and sulphur present.

J. E. Fletcher: I have been very much interested indeed in this paper. I thought perhaps a word or two about our practice in England might be useful to those who were present. In England we have been using the converter process ever since its inception. I may say that the two or three firms who have stood by this process are still successful with it, and are perhaps selling more converter steel in England today than ever they were before.

I thoroughly agree with Mr. Bull's statement that it is largely a question of technique, the care with which the steel furnace is operated and, still more, on the foundry practice, the molding practice and casting practice.

I would like to know whether in the desulphurization that has been mentioned, there is any difficulties with the ladle lining? This discussion has been very useful to me, because we are making a good many experiments just now in desulphurization, and to know that you are dealing with this on the steel making process is very interesting.

Also the point mentioned about raising the manganese is also in accordance with our practice in England. We are finding that the higher manganese gives us much better effects; it takes care of the irregularity

that is always present in sulphur. Sulphur, as far as we know, does not occur quite as homogenously as we should like, but by the addition of larger manganese percentages, we find it takes care of the sulphur much better than with the lower percentages.

I have had much experience with the unannealed side of the question and have had examples of the kind Mr. Bull has mentioned. I have had one or two close escapes from being hit by castings that have been broken during cooling or just after cooling when, while the fetlers were taking some of the flashes off a casting, it suddenly burst under their hands. In England we believe that every casting should be annealed, that is part of our religion in steel castings, I am afraid. We always say to those people who ask the question whether castings should be annealed or not, "Always anneal."

It is rather interesting to note that on our side the electric furnace is not succeeding to the extent that it appears to be succeeding here. The converter steel has quite as good, if not a better, reputation, among our locomotive engineers at any rate, than the electric steel.

CHAIRMAN HALL: This discussion has brought out points about electric versus converter steel and also about percentages of manganese that we steel foundrymen can use, information which comes closer home to some of you gentlemen perhaps than you realize. There are two specifications of the American Society for Testing Materials to which a great many of you either work now or will have to work. In adopting one of those specifications there was a very strong effort made to rule converter steel out of consideration. The other specification is a joint specification of the American Society for Testing Materials and the American Railway Association. In this specification which is now tentative you are forbidden to use more than .80 manganese, and we understand that that specification may be brought up for advancement to standard. In view of this prohibition of high manganese, this paper by Mr. Robinson and the discussion by Mr. Reese and Mr. Fletcher especially on the value of high manganese is of great value. One reason is because those of us who are obliged to carry on the work down there at the American Society for Testing Materials meetings and represent the foundrymen, are going to have some fun with the fellows who are going to tell us how to make castings when they do not make them, they only buy them.

A. H. JAMESON: May I say a word regarding the discussion on sulphur that has been going on this morning? The old problem is give a dog a bad name and hang him. Sulphur has been the scapegoat of all the chemical elements for a great many years and it has never had a fair trial. A few years ago it occurred to some fair-minded people that perhaps it was worth while trying it out and finding just how bad it was. The phosphorus and sulphur joint committee has not reached steel castings yet, but it will. It has done very valuable work on some of the

other steel forms. Mr. Bull is a member of that committee on steel castings, and I think it would be instructive if he would tell us how far they have gone on this program.

CHAIRMAN HALL: Major Bull has a report of that committee to make this morning and I will ask everybody to suspend judgment on sulphur until they hear Major Bull.

D. REESE: I would like to answer Mr. MacKenzie on the subject of excessive deoxidation of converter steel. There is such a difference in the way converters are operated, that I think Mr. MacKenzie has derived his idea from the different methods of operation. We always try to operate near the vertical position. We allow 4 to 10 degrees for the vertical. We have found converters operating—(I am talking about the side blow converters turning out one to three tons) at anywhere from 20 to 30 degrees to the vertical. We find that we get the best operation of our converter when we level up the converter to within 4 to 10 degrees of the vertical.

Our blows last 12 to 13 minutes after the first blow. It is not uncommon to find some converter operators blow the converter 25 to 30 minutes on the same size heats that we are able to blow in 15 minutes. I believe that the same oxidation conditions prevail in a converter as in the open hearth furnace. You are oxidizing carbon and silicon in the open hearth as much as in the converter, except that the reactions occur in the converter within 15 minutes, while it takes hours to go through the same oxidation conditions in the open hearth. It is just a matter of technique throughout. Watch the metal bath, see that the temperature in the cupola is correct, level up the converter, know just where your blow is throughout the whole blow and stop the blow at the right point. As far as I can see, the results from tensile tests ought to tell us quite a lot about the deoxidation. If the tensile tests will compare with other steel, I believe the converter still will compare in oxidized metal as well as the open hearth steel.

Notes on the Operation of a 1½ Ton Electric Furnace Producing a Large Tonnage

By A. W. Gregg* and N. R. Knox,* Milwaukee, Wis.

Introduction

There is nothing novel or original to be set forth in this paper. It is simply a record of the performance of an electric furnace of 1½ tons capacity which has been pushed for output over a period of about a year. It is hoped that the method of operation will prove of value to foundrymen having a furnace of similar capacity, and considerable space has been devoted to a discussion of shop details which do not usually find their way into the text books on electric furnace practice.

Early in 1922 our furnace was installed and for the next 5 or 7 months the usual troubles which beset a new furnace had to be dealt with, i. e., poor refractory life, high electrode and power consumption, etc. Our plant has operated basic open hearth furnaces for a good many years, but we discovered a great many things we did not know about the proper operation of an acid electric furnace.

By a system of trial and error we arrived at our present practice which has now been standard for the past two and one-half years.

Refractory Life

When the furnace was originally lined we burned in the bottom in the usual way. We made a bottom contact for the electrodes with broken pieces of carbon and with a low power input brought the refractories to the glazing point. This was continued about twelve hours, adding an inch of silica sand to the hearth about every two hours until we had a bottom consisting of two courses of brick, a few inches of rammed gannister and five inches of fused silica sand. This bottom has never been removed and we believe it will last indefinitely.

*The Bucyrus Co.

Relining the furnace is always done Saturday or Sunday. A furnace roof or lining is never used after it is reduced to three or four inches of thickness. Heat losses become excessive when the lining reaches this point and the added power cost entailed to produce hot steel far outweighs any further saving in refractory cost by a run of another week or two.

On a lining job, for example, the last heat is tapped at 11:30 A. M. on a Saturday. As soon as the heat is out, the roof is removed by the crane. An air hose is turned into the shell and compressed air left blowing for an hour. Then the lining is knocked in with crow-bars. The hearth is cut and trimmed with air hammers until its rim forms a circle thirteen inches from the furnace shell. The debris is then dumped and swept out and at about 2:30 P. M. the relining is started. Thirteen inches of special shaped silica brick are used. These are laid in loosely and the cracks between each brick and between the brick and furnace shell are filled in with loose silica sand. On the top course is placed two inches of a ganister mixture bonded with fire clay and molasses water. The new roof is then set in position. This ganister mixture forms a seal between roof and lining. The furnace is then charged for the first heat to be run on Monday. On top of the charge is dumped a wheelbarrow load of charcoal. This is ignited and dries out the brick during the week-end. This complete cycle is usually started at noon and the gang goes home at 7:00 P. M. with the job completed.

In laying up the furnace roof, which also consists of special shapes, we insert shingles as expansion wedges, every third brick around the entire ring. These roofs remain on top of a mold-drying oven during the next run of the furnace, which is usually three to four months. This practice we feel is a great insurance against spalled brick.

The usual position for the roof is twenty-one inches above the door sill or bath level. It is our practice to raise it one foot higher and to this end we have bolted an extra ring on top of the shell. According to our experience and after trying various heights, the position just described is the most economical one from the point of view of power consumption, refractory

life and ease of operation for the melter, i. e., when running 5,000 to 7,000 pound heats.

It is a hard and fast rule that the first heat from a new lining shall be melted down, refined and poured with the use of the low voltage tap only. This prevents spalling the brick. After the first heat, the furnace is run as fast as desired.

Refractory results obtained by the above practice are as follows:

Average roof life, last 10 months—1691 tons.
Tons per roof—highest 2362—lowest 1182 tons.
Average lining life, last 10 months—1018 tons.
Tons per lining—highest 1182—lowest 439 tons.

The only patching ever done during the life of a roof and lining consists of crawling in the furnace every Monday morning and mudding up the joint between roof and side walls.

Furnace Operation

As heretofore stated, our electric furnace has a rated capacity of 1½ tons. We have experimented with various sizes of charge ranging from 2500 pounds up to 7000 pounds. Under normal operation our standard heat is 6700 pounds. When pushing the furnace to the limit we find that a charge of 6200 pounds gives us maximum tonnage with greatest ease of operation. For example: In twenty-four hours we can get 9 heats of 6700 pounds, or a total of 60,300 pounds, but with a 6200 pound charge we can get 10 and sometimes 11 heats which gives us 62,000 pounds in the first case and 68,200 pounds in the second case.

We are unable to get these large heats when starting on a new lining. At such times we start with 4500 pounds and boost each heat 500 pounds until we reach our standard. By a judicious use of crushed limestone or mill scale to cut the hearth to its proper bowl shape, we usually reach our objective a day after the new start.

The larger charge, aside from being preferred by the furnace crew because it cuts labor almost in half, is much easier to run accurately due to the slower reactions in a large body of metal, and it also permits greater economy of operation than

with a smaller heat of say 3500 pounds. In addition, it is more convenient for the molding floor to pour a large heat every two hours and 20 minutes instead of a small one every hour and ten minutes.

The following is the log of our average 6200 pound heat with appropriate explanation.

A heat has just been tapped. The hearth and slag line are inspected for holes. If there are any they are filled with damp silica sand. The tapping door is then sealed from the charging side with two or three shovels of foundry sand. This is necessary with large heats and in addition saves the door bottom from burning away. It might be mentioned here that the doors are lined with rammed ganister. With the tapping door sealed and the electrodes run up as high on the masts as they will go, charging is started. This is done by hand as we have never found a chute practical in charging over size heats. The charge consists of 1100 pounds of foundry scrap, 1500 pounds of plate scrap and 3600 pounds of machine or axle turnings. The charging door is banked up half way with silica sand, the furnace tipped slightly forward and the power is turned on. The usual time from power off to power on is 15 minutes.

Log of Average Heat

10:00 A. M Power on.

10:00-11:15 Melting down—high tap 135 volts.

11:15 Power off. Scrap melted and a bath of metal 6 inches deep formed. Three shovels of used sand blast sand added for slag. *Note.* When running a furnace 100 per cent overload it cannot be expected that the charge will melt from the bottom up as is ordinarily the case. The bath forms from the top and works downward. Punchings are to be especially avoided in a charge of this size as they invariably form slugs difficult to get off the bottom. Very fine turnings give the same result.

11:16 Power on. Low tap. 90 volts.
Note. As soon as a bath is formed the furnace is

put on low tap and left there. The use of high tap and the consequent long arc at this stage is the cause of poor refractory life.

11:30 All scrap melted off the bottom.

11:40 Spoon test. Two taken. One broken and fracture read by melter. The other sent to laboratory for analysis to confirm the melter's judgment. *Note.* It is our aim to have the first test read about .24 carbon. This we accomplish by charging 100 pounds of ore. This also promotes the desired boil. From the first test the carbon will drop two to four points by the time the heat is ready to tap. The manganese addition brings the heat back to a final of .25 or .26 carbon. Our range is .24-.30. If the carbon is too low and the bath is cold, we add pig iron. If the bath is hot we dip the electrodes i. e., one electrode immersed 1 inch for one minute gives approximately one point of carbon. Actually, it is largely a matter of judgment of bath temperature as to how much carbon will be picked up by this method.

11:47 Another shovel of sand added to slag. Bath quiet. Slag giving off large bubbles.

11:55 Laboratory check O. K. Spoon test poured for temperature O. K. Manganese added in furnace. Bath dead.

12:00 Silicon added in ladle. Heat tapped.

Every heat, including alloy steels, is held to the aforementioned practice as closely as possible. The following tables show the results obtained. Table 1 shows 10 months operation of the furnace. Table 2 shows results obtained over a period of one week when the furnace was being pushed to capacity.

Explanation of Table 1

Table 1 is a copy of reports furnished by us to the manufacturer of the furnace. We report our monthly figures and four times a year the furnace corporation compiles a sheet showing the

Table 1

DATA EXCHANGE REPORT

	Net Tons Per Month	K. W. H. Per Net Ton	KVA. Demand	Time Per Net Tons In Hours	Net Tons Per Roof	Net Tons Per Side Wall	Electrodes Pounds Carbon Per Ton	Electrodes Pounds Graphite Per Net Ton	Charge Per Heat Net Ton	Time Power Off To On Between Heats Minutes Per Heat	Furnace Rating
Ideal.....	350	550	950	.60	900	1250	12	6	2.5	4	330
Sept.....	668	538	944	.68	....	....	9.67		3.06	5	363
Oct.....	647	580	1008	.70	1530	979	9.19		3.06	5	406
Nov.....	567	562	950	.68	....	439	9.00		3.06	5	382
Dec.....	572	553	912	.68	....	....	9.00		3.04	5	375
Jan.....	584	503	1004.8	.65	....	....	8.40		3.05	5	113
Feb.....	587	588	952.1	.65	2362	1053	9.50		3.10	5	219
Mar.....	671	506	951	.65	....	....	8.30		3.25	5	232
Apr.....	624	530	940	.65	1182	1182	8.70		3.33	5	160
May.....	624	533	953	.65	....	....	8.50		3.23	5	158
June.....	702	506	904.6	.63	....	....	8.50		3.18	5	160
Ave.....	624.6	539.9	902.2	.65	1691	913	8.87		3.13	5	

$$100\left\{\frac{\text{Roof } 900+ \quad \text{Lining } 1250+ \quad \text{Charge } 2.5}{550+\text{K. W. H.} \quad 950+\text{Demand} \quad .600+\text{Time} \quad 12+\text{Carbon} \quad 4\ \text{Time Charge}}\right\}=142$$

results obtained by each operator. The various companies are designated by letters and are unknown to each other. An arbitrary rating is used to place the furnace in the approximately correct sequence, according to their efficiency of operation. The rating formula will be explained later.

Column 1 shows the tons charged; column 2 the K.W.H. per ton. The apparent variation from month to month may be disregarded as it depends largely on when the power company reads the meters. Our average is 539.9 K.W.H. per ton.

Column 3 shows the demand charge. The K.V.A. demand figure that is desired should be given a good deal of thought. On

Table 2

ELECTRIC FURNACE PERFORMANCE
JUNE 15-20, 1925

Heats	62
Pounds Charged	381,974
Tons Charged	190.98
KWH Used	32,664
KWH Per Ton	526.8
Hours Elapsed Time	144.58
Average Time Per Heat	1 Hour 57 Minutes
Hours Melting Time	121.87
Pounds Electrodes per Ton	8.5
Pounds Good Castings	228,000
Tons Good Castings	114
Per Cent Good Castings	59.5*
Tap to Tap—Time	2 Hours 20 Minutes

*Due to open hearth break-down majority of castings poured during week were gears and pinions.

small tonnage and intermittent operation these figures should be kept as low as is feasible. But where a reasonable output may be expected, it is an unfair handicap to a melter to limit him too closely. He is unable to run his furnace efficiently and consequently cannot show economic operation. The above statement should not be taken as advice for an unlimited demand rate. Every user should determine his proper figure aided by the advice of the furnace manufacturer and the power company.

The authors have seen furnaces where the melter was required to keep his demand so low that a heat that should have taken two hours took four and one-half hours. The added K.W.H. input under this sort of operation far outweighs the saving in demand. The demand rate is usually measured over a 15 minute period and we have found it most economical to fix

the point at which, with the furnace pulling its heaviest load, we never have to shut off more than one minute in every 15. This shutting down occurs only when the furnace is on high tap.

Column 4 shows the time per net ton in hours. This is an item that in our opinion calls for judgment and experience. Do not be guilty of urging the furnace operator to run too fast. To keep a heat too long in the furnace is wasteful of power, but to keep it not long enough is to produce inferior steel.

Columns 5 and 6 shows roof and lining life. Good refractory life depends on not overheating the furnace, not laying up the bricks too tightly and the minimum use of such agents as fluorspar and lime.

Column 7 shows electrode consumption per ton of charge. Column 9 shows charge per heat. As mentioned earlier in this paper, it is our experience that a charge in the neighborhood of three tons is the most economical one for a 1½ ton furnace.

Column 10 shows time between heats. It is axiomatic that the less time there is between heats the higher the efficiency shown by the furnace. The deciding factor, however, is the tonnage required. Running single or double turn with a well-trained furnace crew, we average 15 to 20 minutes between heats, power off to power on. This is variable, of course, dependent on the amount of patching required by the hearth. A charging chute or box is a time and labor saver, especially the latter, if the charge is not much greater than the rated capacity of the furnace. But when 50 per cent of the charge is turnings and the total is more than double the furnace standard, hand charging is the only possible method. During the warm months our furnace men charge under a blast of compressed air which blows the heat away from them. This air blast always affords tremendous relief and prevents complete exhaustion, such as often occurred before it was used. The device employed is merely a 3 foot length of 1 inch pipe with ⅛ inch holes drilled in line every two inches along its length. The pipe is supported by 2 foot standards and is parallel with the floor. An air hose is attached and during the charging period a sheet of cool air is blown over the men in the direction of the furnace.

Column 11 shows efficiency rating. This is an arbitrary rating devised merely to group the various furnaces in some relation to each other as regards efficiency of operation and thereby perhaps instill a mild spirit of rivalry.

At first this rating was figured by multiplying K.W.H. per net ton by time per net ton in hours. This method however, disregarded so many items of importance necessary to the proper operation of a furnace, i. e., refractory life, electrode consumption, etc., that after some consideration we suggested a new formula embodying all items of importance. The furnace company accepted this and has put it in use. The formula consists of an equation in which the sum of all items that should be as large as possible, i. e., refractory life and charge, is divided by the sum of all items that should be as small as possible, i. e., K.W.H., demand, time per heat, carbon consumption, and time between heats. Tonnage is purposefully excluded, as that is contingent on business conditions and outside the scope of the melters' activities. Of course, the more tonnage available, the better should be the operation of the furnace.

The ideal figures at the top of the chart were set forth by the furnace company as near the ideal, and the attainment of which would indicate excellent furnace efficiency. In reference to the rating formula previously described, the insertion of the so-called ideal figures therein and the multiplication of the result by 100 to give 3 significant figures, equals 142. The ideal figures are arbitrary, but they serve their purpose very well in creating an incentive; 142 is the figure to obtain or surpass.

Explanation of Table 3

Table 3 shows our metal cost, conversion cost, and total cost of hot metal in dollars per ton of charge. The conversion cost has been limited to the main items of interest and importance, i. e., labor, power, electrodes and refractories.

Our repairs and maintenance are negligible with the exception that once a year we remove the oil from the transformers, clean the cooling pipes inside and out, inspect and tighten all connections, test the coil, and put the transformer back into service again. This is a safety measure and also prevents overheating during the summer months due to a dirty or insulated cooling coil.

Table 3

CONVERSION COST

DOLLARS PER MONTH

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Average
Metal cost per ton charge	14.71	19.29	13.60	15.15	16.99	17.60	15.26	16.23	14.63	13.65	15.70
Melting, including charging, melting and ladle lining	2.20	2.24	2.42	2.26	2.34	2.44	2.12	2.58	2.40	2.28	2.32
Power per ton charge	5.38	5.72	5.77	5.65	5.44	5.87	5.17	5.46	5.48	5.19	5.51
Electrodes per ton charge	.77	.74	.72	.72	.67	.76	.66	.70	.68	.68	.71
Lining refractories per ton, including labor	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.08
Roof refractories per ton charge, including labor	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.04
Total conversion cost	8.47	8.82	9.03	8.75	8.57	9.19	8.07	8.86	8.68	8.27	8.66
Conversion plus metal	23.18	28.01	22.63	23.90	25.56	26.79	23.23	25.09	23.31	21.92	24.37

Table 4

PHYSICAL PROPERTIES OF ELECTRIC STEEL

	Analysis					Test Results			
	C.	P.	Mn.	Si.	S.	Yield Point	Ultimate Strength Pounds Per Square Inch	Elongation Per cent in 2 Inches	Per cent Reduction of Area	Brinell Hardness
1 Low Carbon	.30	.037	.73	.32	.050	44350	76200	28.	42.5	146
2	.28	.030	.71	.32	.049	45250	75550	28.	41.	146
3	.25	.040	.70	.32	.057	44150	68550	33.5	52.	140
4	.24	.043	.60	.34	.049	41300	67800	34.	53.9	134
5	.29	.032	.91	.27	.056	48150	80550	27.5	45.4	150
1. Alloy A	.30	.035	.86	.34	.041	58550	89625	26.	45.4	200
2	.31	.030	.84	.40	.040	66850	109800	20.5	42.2	207
3	.30	.032	.75	.30	.041	69500	114150	19.	41.9	228
4	.31	.034	.76	.37	.045	59150	102650	21.5	36.9	207
5	.31	.028	.99	.46	.046	79350	107000	12.	18.8	228
Alloy B										
1	.27	.039	.78	.47	.039	90450	116600	18.	44.9	
2	.46	.040	.78	.60	.035	108500	144750	10.5	18.1	

Other costs omitted are fuel oil or ladle drying and water for cooling purposes. Water and oil each cost us about 25 cents per ton.

1. *Metal Cost*

Our metallic charge is made up as follows:

20-25 per cent Foundry scrap.

20-25 per cent Plate scrap.

50-55 per cent Turnings, machine and axle; preferably the latter.

We consume all turnings produced in our machine shop, which amounts to 15,000 to 20,000 pounds per day and this reduces our average metal cost as we get these turnings free of freight and handling charges.

2. *Labor Costs*

The furnace personnel consists of a melter, a first helper, two chargers and a ladleman. A similar force makes up the night turn. We always endeavor and usually succeed in having a young man in the first helper position capable of learning to run the furnace and he is taught as quickly as possible and given the opportunity to show his ability. This even extends in some cases to the chargers and ladleman. Consequently we always have a waiting list of intelligent young men who want to get on the furnace.

3. *Power Costs*

Our power cost is decidedly affected by large output and by night and day operation. But also careful charging of a uniform charge, a ***standardized method of running the furnace;*** proper slag consistency and the obtainance of steel temperature sufficient to pour the work required and no more; all these points have important bearing on power costs, also the elimination of roofs and lining as soon as they become so thin that radiation becomes excessive. As stated before, we never allow a roof to get so thin that it burns through.

4. *Electrode Cost*

Considerable care is taken to keep electrode consumption per pound to a minimum. The joint compound is always kept at the

proper consistency and electrodes are joined carefully, not too tight or too loose. The former is liable to cause the nipple to crack off under current load and the latter will cause excessive heating through poor contact. This necks the electrode and increases the possibility of losing the lower half if it receives the slightest jar.

When we run single turn, or for any other reason shut down the furnace, we run the electrode arms as high up the masts as they will go, exposing the hot electrodes to the air so they will cool as quickly as possible. There seems to be some argument as to the best procedure in this effort to reduce oxidation. Some authorities advocate keeping the electrodes down in the furnace and sealing all cracks to prevent drafts.

We tried both methods and were convinced that the faster the electrodes cool the more remained to run another day. Running single turn, our consumption is about two pounds per ton higher than with double turn, i. e., 8½ pounds and 10½ pounds.

5 and 6. *Refractory Cost*

It will be observed that the table does not show cost figures month by month. One reason is that the expense is so small that we do not set up a reserve, and the other is that the insertion of a cost of roof and lining in any one month will be incorrect. Consequently the charges for these two items have been collected and averaged. In an earlier part of this paper our method of operation in relation to roof and lining life was fully explained. It may not be considered amiss to reiterate that it is essential to lay both lining and roof brick so that they have plenty of room to expand. Great care should be taken in bringing the refractories up to heat and never to overheat them by running too long on high tap.

Test Results

Table 4 shows the average physical properties of our electric furnace steel. The castings are all of a rugged nature designed for excavating machinery. The average weight poured from the electric furnace is 50 pounds. All castings are annealed.

DISCUSSION

MR. MACDONALD: Can Mr. Knox give any reason for the figures in the Table 1. The furnace data give the net ton per side wall as greater than the net tons per roof, and our practice has just the opposite effect.

N. R. KNOX: That is perfectly true. I asked the furnace company why they set those figures and I never received a satisfactory answer. As a rule we have never been able to get the lining life from a sidewall that we can get off a roof.

CHAIRMAN J. H. HALL: This is a very important paper, and it very ably follows the precedent Mr. Quinn set last year when he presented a paper giving very full information about the operation of furnaces in his shop. I think the American Foundrymen's Association is to be congratulated on receiving those papers which give so much information. In discussing them, we should keep in mind that what is fair for one is fair for the other. The discussers should give information in exchange for what is given them. There certainly should be some discussion on this most interesting paper.

R. A. BULL: The performance of this furnace under what we might call high pressure conditions has been very interesting; it shows what can be done with this kind of unit. Possibly some who read the performance of the furnace under ordinary conditions and who had not previously read the entire paper, might have been wondering as they were reading along what kind of steel they were making while they were doing all this hurry up work. That is quite fully explained in Table 4, which shows the physical properties of the metal which average excellent. On the last page of the paper itself, there is certainly nothing to be ashamed of with reference to those average physical properties. There is this factor, however, I think in gauging physical results. It is not average conditions so much as occasional bad minimum figures which hurt the foundryman and also the steel man.

N. R. KNOX: I wish to ask Major Bull if he has had any experience in using manganese in preference to putting in the ferro-manganese addition, to control the final results? We admit that sometimes our ferro-manganese jumps around and we are trying to find some way of keeping a closer average condition. We have been thinking of using manganese and we have gone so far as to get some, but have not run any tests on it. I have heard that it has been done.

R. A. BULL: I have had a little experience with it in open hearth and electric practice both. While it is claimed by a number of eminent metallurgists that it is desirable at all times to have a fairly high manganese content in the bath, I have not been able to see that in expensive

open hearth experiments, or in shorter electric experiments of the same kind, that it actually does good.

MR. SEGAL: Do you prepare your turnings in any way or do you take them the way they come?

N. R. KNOX: We take them the way they come. We know the stuff coming out of our machine shops is going to be satisfactory. We buy a larger percentage than we produce ourselves from our machine shop and we find that out of every nine of ten cars we have to reject one car.

MR. SEGAL: You do not press and bale them?

N. R. KNOX: No, recently we used some baled scrap that we were able to get. It was very good stuff and we will probably get some more; it is about $2.00 a ton cheaper than plate scrap.

MR. SEGAL: The variations in manganese and silicon content in electric steel, in my belief, are due to the metal in the heats being hotter. I find that in a heat which has to be very hot, if you are not careful your manganese and silicon will vary. In a very hot heat an operator has to carry his silicon rather high in order to hold his metal in the mold.

MR. DEBONEY: Do you put the manganese and silicon in the furnace or in the ladle?

N. R. KNOX: In the ladle.

MR. DEBONEY: What do you allow for loss of manganese?

N. R. KNOX: Twenty or thirty per cent.

C. E. BALES: I believe that Mr. Knox is to be congratulated on giving us such information as he has on refractories, because on the second page, discussing a relining job, he has answered a number of questions that came up yesterday in the refractories round table discussion. In the opening paragraph he states that this furnace has been pushed for output, and over on page 671 he says, "It is a hard and fast rule that the first heat from a new lining shall be melted down, refined and poured with the use of the low voltage tap only. This prevents spalling the brick. After the first heat the furnace is run as fast as desired." I wonder if his good refractory results are not due to the care he has taken even though he is going for pushed output. I also would like to know if it is the usual practice among steel founders to treat their lining with as much care as Mr. Knox does? I believe if they do, they will get much better results.

N. R. KNOX: We find that if we do not do that we usually get a hundred to a hundred and fifty heats less per run than if we do do it. Now, as I say, we use low taps only, no matter what the foundry foreman wants. On that particular morning he does not get the steel until it is ready to come out. It takes three or four hours. After the heat you

can count every brick in the furnace. They have not been dripped and have not fused together. They just have a glaze.

I say here, after the first heat the furnace is run as fast as desired. Well, sometimes we do and sometimes we do not, and sometimes we carry out that process in lessening degrees for the next two or three heats. After the first three heats we pay no attention to refractories at all and never watch the furnace, but every Monday one of the helpers will crawl inside and see whether the joints between the roof or lining need some mud. We put in a high temperature cement. We throw our roof or linings away when they are about four inches thick; we never let them burn through. When they get that thin, the power starts to go up and it costs a lot more money than refractories.

R. H. WEST: There is no doubt about the value of this paper and I think the electric furnace has been given to the trade for the improvement in the quality of steel. We ran an electric furnace for probably two years. During that period we had considerable trouble in the control of our silicon. Possibly it was the silicon of the furnace that gave us that trouble. Mr. Knox, I believe, made the statement that he is having trouble regulating manganese?

N. R. KNOX: Not always, sometimes.

MR. WEST: Our trouble was experienced on the regulation of silicon. The speaker brings up the question of the regulation of manganese. We all know, those of us who have passed through the converter stage or who are in it, that we can get our silicon and manganese and hit our carbon. If we are losing silicon and manganese in the electric furnace, where is it going? What is taking it up? If oxides are the great trouble in our converters, what is our trouble in electric furnace operation?

CHAIRMAN HALL: At the risk of advertising some member, I would like to point to a report on just that point which Mr. West has brought up. In the publication, *The Research Group News*, of about a year ago, were given results of the control of silicon and manganese in electric furnaces in five plants and showed the possibility of accurate control. Major Bull is more familiar with that chart than I am, and I think he can tell us how closely the manganese and silicon can be controlled in the acid electric furnace with good practice. I am afraid that some of the converter men have forgotten that if you have bad practice, you will have all kinds of variations. Some of the difficulties in controlling composition are not due to the process being used, but to the man who is using it.

R. A. BULL: The plants with which I am associated maintain a range of ten points for what is considered satisfactory control of the silicon and also manganese. We make comparisons of the analyses of all heats kept during the month to see how closely those limits are observed, and those results are all plotted on charts. Every melter receives a

chart showing his own results and those of other melters in these plants. We have been able to get very satisfactory control so that the content of manganese and the content of silicon do not ordinarily go above or below the top and bottom lines that defines these ten point ranges. The explanation of it I think is just what is emphasized by italics in the paper prepared by Mr. Gregg and Mr. Knox, namely, *standardized method of running the furnace*. I think there is no questioning the fact that good control involves a lot of detail and most careful attention to every one of these details. Some means or other, should be found to secure these results possibly by prizes in some cases, in other cases by getting the right kind of man on the job to stimulate the melters to take a real sincere interest in the performance of every one of these operations. In the case of manganese control that we are talking about particularly that involves the accurate sizing of the lumps of manganese so that the oxidation of the ferro-manganese in the bath will, under average normal temperature conditions, be fairly uniform. Thus you can get into the finished product a content that is based on an average loss. It also involves timing the addition of manganese very accurately. It involves in the first place extremely careful weighing of the manganese, not by the use of a scale that is examined about once every six months to see that it is weighing accurately, but one that is systematically examined at short intervals.

Then there is the temperature of the metal, which of course is an important element, the standardization of the operations of the furnace as to high taps and low taps and other conditions. Then the maintenance of the furnace, for instance, as to the desirable extent of erosion or eating away of the lining of the roof resulting in radiation through the walls, which of course in turn affects the temperature of the metal inside, is another factor of importance.

There is no secret about good performance; it is simply paying attention to a lot of details which, if we stop to think about them, all have an important influence on the effect we are trying to get.

E. R. Young: During the last two months I have had the privilege of visiting about 7 electric furnace plants and observing their practices. I find that some people are having some difficulty with variations in manganese and silicon. My observation, coupled with the information they gave me, is that there is some manganese reduction in the electric furnace, depending on how tight the furnace is and to what extent they are run on reducing conditions. Some of these operators run under strictly reducing conditions, excluding all air. The reduction of manganese and silicon is greatly affected by such conditions.

N. R. Knox: I did not mean to give the impression that we could not control our manganese; we think we can although we do not do it quite as closely as we want to. We analyze a heavy heat. Place the data on a chart and discuss the data with the melters. We compare results

month by month and sometimes day by day, and it does a lot of good. It gives the melters a much better idea of what they are doing and tends to make them more careful, if you show them a chart where, running across the sheet, you have carbon, silicon and manganese. We have two open hearth furnaces and an electric furnace and there is a little friendly rivalry to see who is going to run with the least deviation.

MR. BURKE: Why is it essential to control manganese in carbon steel within a ten to fifteen point limit. This, I gather from the discussion here, is essential.

R. A. BULL: I did not mean to imply that it is absolutely necessary for good steel to be controlled within a ten point limit; what I did say was that we consider such control satisfactory melting practice. I believe it is because we have all of us a great deal of respect for the influence of manganese, for we know that a variation of any extent will result in a difference in physical properties and we are trying to make a uniform product.

CHIARMAN HALL: We know what the manganese is that we want, and the nearer we can get to it the better we are saisfied. I think the question you have in mind is the influence of variations in straight manganese.

MR. BURKE: No, I have carbon steel; what is the benefit of running the manganese up to one or one and a half per cent in carbon steel? I have heard considerable discussion about running the manganese up that high.

CHAIRMAN HALL: Does anyone want to answer this question, what benefit do you derive by raising the manganese?

S. R. ROBINSON: We never get up as high as one and a half per cent. We try to run from .75 to 1 per cent, and in that case we keep the carbon down. We feel that working as we do to an "as cast" specification on the physical properties of the steel, coupled with the quality of the steel, action in the mold and freedom from cracking, that we can get better results with the carbon around .20 and the manganese around 1 per cent than we can get with the carbon around .27 and the manganese around .60.

R. A. BULL: I saw an interesting article by our chairman, Mr. Hall, on high manganese steels, in which he summarized the results of many tests, over a thousand I should say, all of which gave a great deal of information as to the properties you can expect from carbon steel containing a 1.25 per cent manganese.

Making Miscellaneous Steel Castings for Navy Use

By D. F. Ducey,* Puget Sound, Wash.

Our navy yards exist primarily for service to our fleet. Service involves repairing, docking, improving and furnishing supplies and spare parts. By the term fleet is meant all combatant and non-combatant vessels that are employed in the prosecution of war. The fleet is composed of battleships, cruisers, torpedo-boat destroyers, submarines, air and sea-planes, hospital-ships, colliers, oil-tankers, and supply-ships.

We are all familiar enough with these various types of vessels to know that they are equipped with propulsive machinery of nearly every kind known to marine engineers.

On the battleships, destroyers, and cruisers there are turbines, generators and motors ranging from five to ten thousand horsepower. On the submarines will be found heavy oil engines. The noncombatant vessels, supply-ships and the like are usually propelled by reciprocating engines.

Each vessel must, of necessity, have a complete installation of main propulsive unit auxiliaries, such as pumps, condensers, heaters, coolers, etc.

Then there is the armament or ordnance of the combatant vessels; guns, firing shells that weigh from one to two thousand pounds, their mounts, barbettes, turrets; the ammunition supply facilities; the numerous and intricate fire control and ship-control devices; the plane catapults, and the torpedoes and their tubes.

To man the engines and armament these vessels have complements varying from fifty to fifteen hundred men. As each vessel must be self-sustaining over long periods, the crew must be housed and provided for in much the same manner as the guests

*Lieutenant Commander, U. S. Navy Yard, Puget Sound.

of a hotel. There must be supplied water, lighting, food, cooking facilities, medical attention, and other such necessary requisites.

To each navy yard there is assigned a number of vessels of the fleet. The assignment of vessels is varied from time to time. Sometimes a navy yard may handle the work of battleships or destroyers only; at other times one or several vessels of every type may be assigned to the same navy yard.

Peace Time Schedule

During peace times there is carried out a pre-arranged schedule of docking and repair; each vessel goes to a navy yard for a certain definite period.

For the repairs of the vessel during this period there is allotted a fixed amount of money. The total amount of money allotted to any one vessel depends on the amount of money available as appropriated by Congress, and the needs of the vessel as compared to other vessels of the fleet. As the amount of money available for any one vessel is limited, in order not to spend more than this amount, there being no surplus, the cost of each individual job must be estimated in advance. If the costs of any job exceed the estimates, some other job is left uncompleted. All such instances entail an investigation.

The fleet must train, and maneuvers, steaming trials, gun and torpedo practices must be carried out. As several vessels are assigned to form a unit for these exercises a pre-arranged schedule is a necessity. If the period of overhaul at a navy yard for any vessel is extended, the operation of other vessels is affected. To prosecute fleet training to the fullest extent overhaul periods are restricted to shortest possible periods. So much for peace times.

In time of emergency, war, there is usually an ample supply of funds, the time element then becomes the predominating factor. Where the "rush" job was an exception, it now becomes the rule. While during peace economy dominates time, during war there is never "time enough." But, come what may, there is required the highest class of work so that dependability, the primary requirement of any fighting unit, may be assured.

Varied Work for the Navy Steel Foundry

As each vessel of the fleet is a development of a previous vessel, it is seldom that two exactly alike are ever encountered. An exception to this is in the destroyer and submarine classes, where there are from five to forty-five vessels in the various classes. This results in there being a very small proportion of "repeat" jobs, that is, jobs that can be standardized.

Among the diverse establishments maintained at a navy yard for effecting repairs to the fleet is the steel foundry.

A navy yard steel foundry, unlike the average commercial steel foundry that selects a certain line of manufacture, cannot choose its work, but instead must accept what the fleet provides. The commercial foundry may specialize in light, medium, or heavy work; its efforts may be confined to a limited number of grades of steel. Under such conditions experimentation is most logical, and there is ultimately derived a "best method." The fleet provides a field so large and ever progressive that except in the case of standard fittings, such as valves, flanges, etc., any extensive experimenting with the view of establishing a "best method," is out of the question. Each individual case becomes a problem that must be solved at the time.

Some navy yards are located close to large steel industries; such yards can rely to some extent upon the commercial foundries for certain classes of castings. Other yards, not so situated, must depend entirely upon their own resources.

On commercial vessels cast iron is used extensively. On combatant vessels, where weight is always at a premium and high pressures are the rule, steel is in general use. All main and auxiliary steam line valves and fittings must be of steel, as must all other units subjected to line steam, for the reason that superheated steam is in general use. Turbine casings are of steel, and the hull itself requires large steel castings, such as the stern and stem castings. The number of smaller steel castings, from one pound up, that may be required at any time, runs into the thousands. While the weight of individual castings averages two hundred pounds, there is required, from time to time, castings that weigh as much as fifteen tons.

Space on board ship is limited, the hull shape, for obvious reasons, is fixed. In installing the various units in the vessels, it is found that where ordinarily it could be expected to use a simple shape, the configuration is such that an intricate shape must be used.

Demand for Castings Varies

The demand for steel castings by the fleet is by no means constant. Where alterations are concerned, the requirements are known in advance. Under these conditions molding, melting ,etc. can be systematically carried out. Ordinarily, "jobbing" prevails. During one week there may be required six or seven tons of steel; then for the following month but one ton will be required. This latter amount may be required in one heat; or emergency conditions arise such that four or five separate heats will have to be run. As typical of the fluctuating load handled by the steel foundry the following data is quoted:

Good castings in high month, 220,000 pounds.

Monthly average during past year, 27,840 pounds.

Low month during past year, 2,423 pounds.

Total during past year, 143,674 pounds.

During the low month 121 pieces, average 20 pounds each, were cast. During the high month 103 pieces, averaging 270 pounds each, were cast. The largest single steel casting weighed 26,000 pounds; the smallest 2 ounces. To furnish such an assortment of castings and furnish them at a minimum cost under conditions as outlined above, is the problem with which the foundry is confronted. How, in a general way, the problem is handled at one navy yard will now be taken up.

Equipment of Foundry

There is one shop; this shop handles both the ferrous and non-ferrous metals. It is equipped with tracks, traveling cranes, fixed cranes, core oven, sand blast, flask repair facilities, mixing machines, flasks, ladles, testing and analysis apparatus, pits, etc., that are used in common for both ferrous and non-ferrous metals.

For steel there is a one-ton converter and a six-ton electric furnace. This latter furnace, though only rated at six tons capacity, easily handles ten tons, and on occasions, with the charging doors and pouring spout banked, fourteen tons have been melted; by adding to this three blows from the converter, it has been possible to get a maximum single pouring consisting of the fourteen tons plus three times the converter capacity.

Green Sand Facing Developed

The shop was originally designed and built for an iron and brass foundry. During rush periods it was found that the core and mold drying ovens were not of sufficient capacity to handle the requirements for iron and non-ferrous metals, let alone attempting to dry the steel molds. This led to the development,

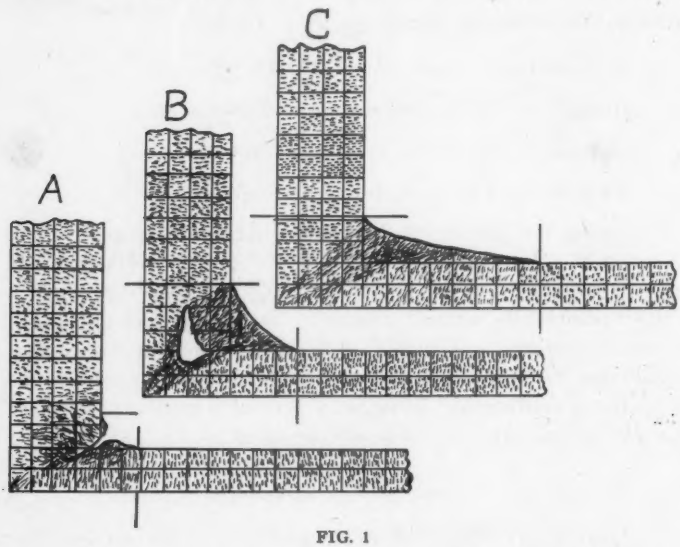

FIG. 1

by the master molder, of a green sand facing, consisting of the best grade of silica sand bonded with a minimum of high grade fire-clay. The sand and fire-clay were tempered with molasses water and a small amount of crude oil added. This facing while

limited in its application, was applicable to the extent of tiding over the rush periods.

Filleting Important

Of the "rush" jobs encountered, high pressure steel valves and fittings form no small proportion. Improper filleting and uneven distribution of metal produces a valve that is like a case of hives to the operating engineer. Fillets that were considered satisfactory in the pattern shop produced cracks in the castings unless the molder happened to be sufficiently experienced to cut heavy fillets in the mold. Such heavy fillets, used at random, while preventing surface cracks, often resulted in shrinkage pockets.

In view of the import of obtaining a satisfactory, dependable valve at the first casting, a fillet, shown at C Fig 1, was developed. The fillets shown at A and B proved unsatisfactory. In casting the ordinary run of valves, both large and small, this fillet, C, has obviated the use of brackets or chills; the latter are only resorted to when there is a radical difference in the sections to be joined.

Location of Gates and Risers

It was also found that the location of gates and risers played no small part in the elimination of cracks and distortion of the castings. A seven-inch high pressure steel angle valve, molded similar to the seven-inch globe valves that had proved very satisfactory in the past, resulted in several rejections. By relocating the gates a satisfactory valve was obtained, and subsequently no further difficulty was experienced with this special type of valve. Other classes of castings that had a tendency to warp or deviate from their natural position were held in proper alignment by a judicious allocation of risers and gates.

The above devices are submitted as being illustrative of the methods employed in handling the divers problems that arise from time to time.

Planning and Routing

For purposes of showing the procedures followed in planning, routing, tracing and cost accounting, the following example is given:

N. S. O. 166 Puget Sound Navy Yard 3-24 50M (A-30)

"A"

WORK REQUEST ..... (Serial Number) ..... (Group Name) ..... (Group Number)

U. S. S. ..... (Dated) ....., 192

REPAIR ..... URGENT ..... DESIRABLE ..... **ALTERATION** ..... Bureau Having Cognizance

Check with X as applicable

To: THE CHIEF OF BUREAU OF .....

THE COMMANDANT, NAVY YARD .....

VIA: (1) ..... (2) ..... (3) ..... (4) .....

(Use abbreviation)

The following work, beyond the capacity of the ship's force, is requested:

See Below:

Signed ....., U. S. N., ... Commanding

JOB ORDER 601b5101-3039 **U. S. NAVY YARD PUGET SOUND**

INCIDENTAL TO ..... 6-5-25 ....., 192

TITLE D APPN Eng.Bu.Eng. 1924-25 Subhead 1 Ship or Object U.S.S. Doyen

SPECIFICATION: GROUP NAME Boilers

AUTHORITY: Bu.Eng. Let -----

Renew six auxiliary steam valves on boilers 1,2,3 and 4 in accordance with Bureau Engineering Plan 251-Q-079.

Estimate No. 79647 Estimator Smith Checked by Harris

I. 220 I 90 M 90 T 400 DAYS 10

J. O. APPROVED: Doe

WORK COMPLETED: Raven (Supt.)

WORK SATISFACTORY: Jones (Ship Insp.)

FIG. 2

Six non-standard high pressure steel valves are required for a vessel undergoing repair. The order is forwarded to the chief estimator and planner who assigns the task to an assistant. The assistant estimator consults with the various shops concerned, investigating the job from all angles. He then proceeds to draw up a complete estimate and analysis of the job. Each shop concerned is allowed a specified number of man days and a specified amount of material to complete their part of the job. This analysis and estimate, after being checked by the chief estimator, is assigned a job order number which designates the appropriation that the job is to be charged against, the vessel concerned, the classification of the work to be done, the serial number of the job under such classification, and the title.

Forms Used

The analysis, estimate, and scheduling is embodied on three forms, shown herewith, and designated as A (Fig. 2), B (Fig. 3) and C (Fig. 4). The upper half of form A is for making a record of the request as submitted by the vessel requiring the work. Referring to the lower half, the first three digits, 601 designate the appropriation against which the work is to be charged; the letter D indicates whether the work is repair, alteration, or special project; 51 designates the classification, such as boilers, main engines, etc., 01 indicates that this is the first job order under the classification, 51 that it has been issued during the vessel's present overhaul, and 3039 is the vessel's accounting number. On the reverse of form A, the actual charges are entered, to be checked, as desired, against the estimated changes.

On form B (Fig. 3), the column headed "men days" is left blank in the copies sent to the shops, but the estimator uses it in arriving at his total estimate as entered on form A. The columns "Date to complete" and "Date completed" are filled in by the progress section, as will be described later.

Form C (Fig. 4) constitutes a synopsis of the job, and is used by the progress section in checking the job, in routing and scheduling other jobs.

With regard to the job shown on the forms A, B, and C, form B informs the foundry that on the 9th of June it will be required to proceed with the casting of six auxiliary steam valves as per a certain plan, and that the valves must be ready for delivery to the machine shop by the end of working hours on the 12th.

ID79 1-30 7M

WORK ORDER BRIEF

Est. No. 79647

Job Order No. 601D51Q1-3039 Ship. Doyen Date 6-5-25

Renew six auxiliary steam valves on boilers 1,2,3 and 4 in accordance with Bureau Engineering Plan 251-C-079.

Charge No.	Shop Section	Men Days	Date to Complete	Date Completed	M	Remarks
1	X94		6-8-25			Provide pattern.
1	X81		6-12-25			Provide castings, tag to x31.
1	X31		6-17-25			Machine, test, deliver to x72.
1	X72		6-17-25			Deliver to x38.
1	X38		6-19-25			Install.

Shop: When completed, sign and send to Superintendent. .....Foreman. Date.....

Superintendent: Date and send to Program Group. .....Supt. Date.....

ID79 1-30 7M

WORK ORDER BRIEF

Est. No.....

Job Order No. ..... Ship..... Date.....

Charge No.	Shop Section	Men Days	Date to Complete	Date Completed	Remarks

Shop: When completed, sign and send to Superintendent. .....Foreman. Date.....

Superintendent: Date and send to Program Group. .....Supt. Date.....

FIG. 3

All jobs are handled in a similar manner, and when possible, are issued well in advance, so that the foundry can regulate the running of heats. In addition to the above the foundry keeps in personal touch with repair work in hand, as an additional preventive against having to run special heats.

Forms A, B and C, partially completed, after being approved by the chief estimator, are sent, in the rough, to the progress sec-

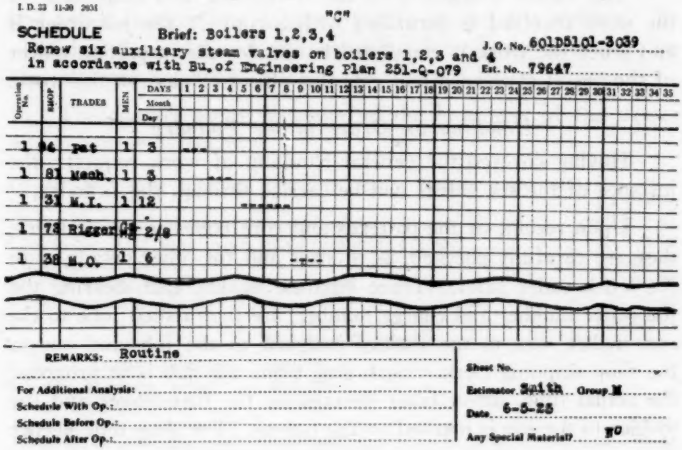

FIG. 4

tion. Here, routing and completion dates are scheduled. These dates are based on the comparative urgency of the contemplated work, the volume of other work under way, the date of completion of the vessel for which the work is being done, etc.

Scheduling completed, the job is written up in the smooth, and copies of the work briefs, B, are sent to all shops concerned, to the offices concerned, and to the accounting department. It will be noted that on the work brief, which goes to the shops, no estimate is included; the shops are given instructions and a completion date only.

Upon receipt of the work order brief, if the shop master sees that he cannot meet the designated date of completion, he takes the matter up at once so that the subject of working shifts or extending the date may be gone into immediately.

Forms A and B are not sent to the shops, but retained in the main office for further compiling. The original of the work order brief is retained by the progress section for checking progress and completion dates.

The officer charged with the overseeing and inspection of the work involved is furnished with a copy of the job order B and when the work is completed he notifies the inspection officer of the vessel concerned and gets this officer to pass on the work.

Handling on Order in the Foundry

Having covered the general handling of work requests, the instance of the six valves will be carried through the foundry.

Upon receipt of the patterns and core boxes in the foundry, they are carefully checked, as to sizes and for other details, with the work order brief. Three separate tickets, each bearing the job order number and charge number, are then issued; one to the core-maker, one to the molder assigned to the job, and one to the shop shipping clerk. Each day, while this job is in progress, the actual time, direct labor devoted by the core-maker and the molder to the job is marked on the tickets. The shop time keeper then transfers the times to the clock punched time cards.

The daily time card carries the man's number, the number of each job order he has worked on during the day, and the number of hours worked on each of the job orders. A designating shop expense number is also carried on the card. These daily time cards are sent to the accounting department each morning before nine o'clock.

When the valves in question are finished in the foundry, which includes chipping and cleaning, the shop shipping clerk weighs them and gets a receipt from the machine shop, where the valves are delivered. The progress section is informed of this completion date and the weight data, with its designating job order, is forwarded to the accounting department.

Determining Costs

The accounting department then assembles all time cards having charges against the valves, adds to the total direct labor thus obtained, the steel molding overhead and obtains the total cost of the valves by adding the material charge. Material charges are at so much per pound of metal, and are made up of direct material costs plus melt overhead. These charges are compiled from running record of metal used, furnace losses, fuel consumption, gates, sprues, risers, overmelt, and all maintenance, upkeep, and other charges that appear directly against the melting. In obtaining the mold and melt overhead some thirty odd expense accounts are involved.

The charges going to make up the total cost of the valves would appear as follows:

Check No. 8121 making cores to valve bodies and bonnetts; 9 hours	$ 8.82
Check No. 8127 making 6 valve bodies; 8 hours	7.84
Check No. 8142 molding 6 valve bonnets; 4 hours	3.92
Total direct labor	20.58
Steel molding overhead, 150 per cent	30.87
Total molding charge	51.45

Material Charges

6 valve bodies, weight	660 lbs.
6 valve bonnets, weight	240 lbs.
Total weight,	900 lbs.
Total cost at 4 cents per lb	36.00
Total labor and material; final cost	87.45

Defective castings are a charge against foundry shop expense. Should a certain amount of machining be done on a casting before the defect is discovered, the cost of this machining is also a charge against foundry shop expense.

After the final costs are tabulated, the individual charges are checked with the estimates. Discrepancies are investigated and the record of the job is filed for reference in estimating on similar jobs.

At the end of each month all navy yard foundry expense accounts are summarized and transmitted to the navy department in Washington. This office then compiles data sheets, which are forwarded to all navy yards, showing the relative standing as regards costs, of the several yards.

Report of Committee on Specifications for Steel Castings

To the Members of the American Foundrymen's Association:

The report of your committee last year called attention to the fact that the American Society for Testing Materials had, during the year, appointed a Sub-committee XXII of Committee A-1 to draw up specifications for "Carbon Steel Valve Castings for High Temperature Service."

During this last year that sub-committee was very active, held several meetings, all of which were attended by two members of this committee, Messrs. Bull and Jameson.

The final result was a compromise as is almost inevitable in such cases and the final draft of the tentative specifications was approved by Committee A-1, presented to the general meeting of the American Society for Testing Materials in June, where it was finally approved. It now stands, therefore, as a tentative standard for the present year. A copy follows this report as Appendix "A".

It is highly important that all of our members who are interested in the production of steel castings for steam pressure work should familiarize themselves with the specifications, try them out in actual practice, and be prepared to express their opinions upon them next June when they come up before the general meeting of the A. S. T. M. to be adopted as standards, or revised, or perhaps continued another year as tentative merely. The committee regrets to report that the members of the American Foundrymen's Association have not come forward with the suggestions which it had hoped. Your representatives on the committee that framed them feel that the compromise which was finally reached is far from perfect. We hope that now they are published and broadcasted there will be a lively interest evinced and that we may have the assistance of the advice and counsel of all of our fellow members,

many of whom will find themselves expected to work under these specifications when, or if, they are adopted as standards.

This highly important specification is the only one which has been under active consideration during the year and your committee has, therefore, nothing further to report in the way of progress.

Respectfully submitted,

A. H. JAMESON, *Chairman*
A. F. A. Committee on Specifications
for Steel Castings.

APPENDIX A

(Report of Committee on Specifications for Steel Castings)

PROPOSED TENTATIVE SPECIFICATIONS FOR CARBON-STEEL CASTINGS FOR VALVES, FLANGES AND FITTINGS FOR HIGH-TEMPERATURE SERVICE[1]

Serial Designation: A 95 – 25 T

This is a **Tentative Standard** only, published for the purpose of eliciting criticism and suggestions. It is not a Standard of the Society and is subject to revision.

ISSUED, 1925, BY AMERICAN SOCIETY FOR TESTING MATERIALS.

Material Covered. 1. These specifications cover carbon-steel castings for valves, flanges and fittings for service up to 400° C. (750° F.) total temperature.

1. *Manufacture*

Process. 2. The steel shall be made by one or more of the following processes: open-hearth, electric-furnace, converter, or crucible.

Heat Treatment. 3. (*a*) All castings shall receive a heat treatment proper to the design and chemical composition of the castings.

1. Criticisms of these tentative specifications are solicited and should be directed to Mr. G. H. Woodroffe, Secretary of Committee A-1 on Steel, Parkesburg Iron Co., Parkesburg, Pa.

(b) Heat treatment, unless otherwise specified by the purchaser, may consist of annealing, or of normalizing, or of normalizing followed by annealing, or of normalizing followed by a draw-back to a temperature below the critical range. No castings which have been quenched in any liquid medium shall be offered under these specifications.

(c) Annealing.—The procedure for annealing shall consist in allowing the castings to cool after pouring, to a temperature below the critical range. They shall then be uniformly reheated to the proper temperature to refine the grain and allowed to cool uniformly in the furnace.

(d) Normalizing.—The procedure for normalizing shall consist in allowing the castings to cool, after pouring, to a temperature below the critical range. They shall then be reheated to the proper temperature to refine the grain and allowed to cool in still air.

II. *Chemical Properties and Tests*

Chemical Composition. 4. *(a)* The castings shall conform to the following requirements as to chemical composition, except that the following limitations for carbon, manganese and silicon are intended to show desired composition and are not be used for rejection:

Carbon	0.15-0.40 per cent
Manganese	not under 0.50 "
Silicon	not under 0.20 "
Phosphorus	not over 0.05 "
Sulfur	not over 0.05 "

(b) Manufacturers submitting proposals to furnish material under these specifications shall specify, with their proposals, the limits of carbon, manganese and silicon which they will accept as a basis for rejection.

Ladle Analyses. 5. An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of the elements specified in Section 4. This analysis shall be made from drillings taken at least ¼ in. beneath the surface of a test ingot

obtained during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements specified in Section 4.

Check Analyses. 6. Analyses may be made by the purchaser from the broken tension test specimen or from a casting representing each melt. The chemical composition thus determined shall conform to the requirements specified in Section 4. Samples for analysis shall be taken not less than ¼ in. beneath the surface, except in the case of castings which are too thin, and shall be taken in such a manner as not to impair the usefulness of the casting.

III. *Physical Properties and Tests*

Tension Tests. 7. *(a)* The castings shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in.	70 000
Yield point, lb. per sq. in.	36 000
Elongation in 2 in., per cent	22
Reduction of area, per cent	30

(b) The yield point shall be determined by the drop of the beam of the testing machine at a cross-head speed not to exceed ⅛ in. per minute. The tensile strength shall be determined at a speed not to exceed 1½ per minute.

Bend Test. 8. *(a)* Bend tests shall be required for castings only when so specified in the order.

(b) When a bend test is specified, the test specimens shall stand being bent cold through an angle of 90 deg. around a pin 1 in. in diameter, without cracking on the outside of the bent portion.

Test Specimens. 9. *(a)* Tension test specimens, and, when a bend test is specified, bend test specimens, shall be taken from test bars cast attached to the castings where practicable. If the design of the castings is such that test bars should not be attached to the castings, the test bars shall be cast attached to special blocks, a sufficient number of which shall be provided for each lot of castings.

Test bars from which tension and bend test specimens are to be taken shall remain attached to the castings or blocks they represent through heat treatment and until presented for inspection. Test bars shall be provided in sufficient numbers to furnish the tests required in Section 10.

(b) If satisfactory to the manufacturer and inspector, tension test specimens may be cut from heat-treated castings, instead of from test bars.

Tension Test Specimens. *(c)* Tension test specimens shall conform to the dimensions shown in Fig. 1. The ends shall be of a form to fit the holders of the testing machine in such a way that the load shall be axial.

(d) Bend test specimens shall be machined to 1 by ½ in. in section with the corners rounded to a radius of not over $\frac{1}{16}$ in.

Number of Tests. 10. *(a)* One tension test and, when specified, one bend test shall be made from each melt in each heat-treatment charge and, when specified, from each casting weighing 500 lb. or over.

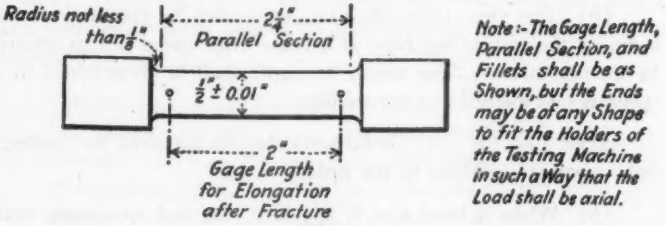
Radius not less than 1/8"
2 1/4"
Parallel Section
1/2" ± 0.01"
2"
Gage Length for Elongation after Fracture
Note:-The Gage Length, Parallel Section, and Fillets shall be as Shown, but the Ends may be of any Shape to fit the Holders of the Testing Machine in such a Way that the Load shall be axial.

FIG. 1

(b) If any test specimen shows defective machining or develops flaws, it may be discarded; in which case another specimen from the same lot shall be substituted.

(c) If the percentage of elongation of any tension test specimen is less than that specified in Section 7 *(a)* and any part of the fracture is more than ¾ in. from the center of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

Retests. 11. If the results of the physical tests for any lot do not conform to the requirements specified, such lot may be re-treated, but not more than twice. Retests shall be made as specified in Sections 7 and 8.

IV. *Workmanship and Finish*

Workmanship. 12. The castings shall conform substantially to the shapes and sizes indicated by the patterns and drawings submitted by the purchaser.

Finish. 13. *(a)* The castings shall be free from injurious defects.

Welding. (b) Defects which do not impair the strength of the castings may be welded by an approved process. The defects shall be cleaned out to solid metal, before welding, and when so required by the inspector, shall be submitted to him in this condition for his approval. All castings shall be heat-treated after welding in accordance with the requirements in Section 3.

V. *Inspection and Rejection*

Inspection. 14. *(a)* The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the castings ordered. The manufacturer shall afford the inspector, without charge, all reasonable facilities to satisfy him that the castings are being furnished in accordance with these specifications.

(b) If, in the case of important castings for special purposes, surface inspection in the green state is required, this shall be so specified in the order.

(c) All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection. 15. *(a)* Unless otherwise specified, any rejection based on tests made in accordance with Section 6 shall be

reported within five working days from the receipt of samples.

(b) Castings which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected and the manufacturer shall be notified.

Rehearing. 16. Samples tested in accordance with Section 6, which represent rejected castings, shall be preserved for two weeks from the date of transmission of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

DISCUSSION

CHAIRMAN J. H. HALL: The A. F. A. representatives on these A. S. T. M. committees frequently have a hard fight on their hands in representing the foundrymen. I think perhaps the men that they represent do not realize how much stronger their position is if they have had good suggestions and criticisms from the members, of the existing standards. If the representatives can go to these committee meetings and meet the producers with a stack of letters in their hand from foundrymen saying, "This is not acceptable," or criticizing some feature or making suggestions, their position is infinitely stronger in meeting the demands of the consumers which are often unreasonable. The A. F. A. representative does not feel half so lonely if somebody writes him a letter once in a while about his work. This report will be received and printed for distribution as usual.

Report of A. F. A. Representative on Joint Committee on Investigation of Effect of Phosphorus and Sulphur in Steel

To the Members of the American Foundrymen's Association:

Contrary to custom, there was not a meeting of the entire joint committee during the convention of the testing society, held in June, 1925. Furthermore, there was not presented at that convention a preliminary report of the joint committee covering recent activities. A meeting of the advisory committee, consisting of the chairman of each of the sub-committees, was held during the convention referred to. The minutes of meetings of this character and of subcommittees are distributed to all members of the joint committee.

The work of the joint committee, during the year that has expired since the last convention of the A. F. A., has been, as before, exclusively related to the investigation of sulphur in steel. The research into the effects of phosphorus has not yet been started, due to the very large amount of work required for determining the influence of sulphur, the first of these elements selected for investigation.

It is expected soon that the Association of American Steel Manufacturers will be able to supply material representing rail, tire, and wheel steels if, by the time your representative's report is presented, such steels have not already been furnished by the association mentioned. There was some unanticipated delay in securing these steels, and this has prompted efforts to collect for test purposes at an early date, specimens in Series A, Group VI, by which classification steel castings are designated. Dr. Langenberg, chairman of the Sub-Committee on Tests, has recently been giving consideration to a test program to cover this class of material. Of course, it is this phase of the phosphorus and sul-

phur investigation in which the members of the A. F. A. are particularly interested.

It is possible that a communication on the phase of the joint investigation relating to steel castings might, at a fairly early date, be published in the A. F. A. Bulletin, or be transmitted to those members of the A. F. A. who are engaged in steel casting manufacture. Your representative on the joint committee will keep in close touch with the developments in this matter so as to give you early authorized information of any circumstances of which you should be promptly advised.

It may be recalled that the last published preliminary report of the joint committee, covering rivet steels, contained no conclusions reached by the joint committee. It is possible that conclusions may be reached and announced later as the result of the comprehensive tests on the rivet steel material. Purposely, the members of the joint committee have displayed a great deal of caution in individually arriving at conclusions. No effort has yet been made for the purpose of ascertaining or harmonizing such individual conclusions as may have been reached so that these may ultimately be published as representing the viewpoint of the joint committee.

According to the tentative program arranged some time ago, one class of materials selected for tests was that of spring steels. It is possible that the investigation of this material may be deferred for the purpose of giving earlier consideration to steel castings.

Respectfully submitted,

R. A. BULL, *A. F. A. Representative,*

Joint Committee on Investigation of Phosphorus and Sulphur in Steel.

DISCUSSION

R. A. BULL: Since I dictated that report, I received a letter from Dr. Langenberg in which he said there would be an early meeting called of the sub-committee on tests, at which time it was hoped that a definite program covering the tests on steel castings would be made.

CHAIRMAN J. H. HALL: The A. F. A. representatives on the A. S. T. M. committees have quite a lot of work to do and in this particular case the investigation of the influence of phosphorous and sulphur on steel, we are getting right close to home. Within the next year they will be investigating the influence of sulphur on steel castings, and the A. F. A. representatives I know wish the assistance of the members of this association, and any suggestions they have for their guidance in working on this joint committee. They do not want to feel that they are carrying a load all by themselves, entirely from their own ideas and their own knowledge. What action do you wish to take with this report, Major Bull?

R. A. BULL: I think it might just be filed, together with any comments that the members feel disposed to make on the subject. Of course, up to this time investigation has related to materials in which we are not commercially interested from the standpoint of the foundry. Now we are getting down to brass tacks soon and I certainly hope that all the members of the American Foundrymen's Association who make steel castings will follow the matter with appropriate interest. We know, of course, that the influence of sulphur is considerable, on castings. What this joint committee is trying to do is to find out what the effects of phosphorous and sulphur are on the material. Some of those steel foundrymen who make nothing but large castings may feel that it is to a certain extent time lost from the standpoint of the foundryman to go into investigations of this kind. There are, however, many steel castings made of such design as not to be naturally susceptible to shrinkage cracks. There are some of them that, if they had .10 sulphur you could hardly crack if you wanted to. Thus there is an application for many cases of steel castings which, if we can make them successful in our shop and when they go to the consumer, give satisfactory service, we will all want to know about it.

MR. SEGAL: In regard to sulphur and phosphorous in the large difficult castings which I have made myself, I find that if I go around .035 in phosphorous I find no cracks whatsoever in large castings. In making this assertion I can say that in making a locomotive frame for Henry Ford (now installed on one of his largest locomotives), you will find the same analyses not only on that casting but on all large difficult castings which have thin and heavy sections. By overcoming chilling through your heavy and light section, you have to carry phosphorous and sulphur around those points.

CHAIRMAN HALL: This is not a report on the influence of phosphorous and sulphur in steel, but it is a report on the work of the committee investigating it. Many ideas that we have individually our representative would be very glad to have for his guidance in working on this joint committee.

A Method of Treating and Handling of Molding Sand

By Max Sklovsky,* Moline, Illinois

By the ordinary methods a molder handles forty times as much weight in sand as compared with his production in castings. In the dumping process the sand is handled to the extent of nine times the weight of the castings produced, and in cutting the sand eighteen times as much weight is handled as is produced in castings. In total, therefore, the sand handled daily by labor is sixty-seven times that of the tonnage of castings produced.

In heavy production it is obvious that the tremendous effort required in handling the sand must be accomplished by mechanical means in place of manual labor. Various methods have been developed for accomplishing this, using in most cases elaborate and expensive equipment. The endeavor in the present case has been to develop a method of power handling of sand, and that it be simple enough and low enough in cost to apply in a unit system; that is, a method of sand handling and sand treatment which would apply to a single molding unit.

A description of this method can best be presented by a series of photographs. Before, however, describing the handling of sand, it is preferable to indicate the general scheme of foundry operations as related to the particular unit. In this unit the aim has been as follows: (1) To operate on the basis of progressive production by the usual division of molding, core setting, pouring, dumping and sand cutting, wherein each member of the production crew performs a single class of operations; (2) by applying devices and equipment for each class of operations to handle the work in the most effective manner, eliminating as much as possible the manual effort; (3) to apply to all elements of the scheme, including the sand itself, the principle of continuity.

The foundry in this case in which the molding outfit is located is a two-story building in which metal is melted throughout the

*Deere & Co., Moline.

day, permitting thereby the pouring of the castings as frequently as is desirable. The molding and pouring are located on the upper level and the sand cutting is accomplished on the lower level. The molds are dumped and the poured castings in the sand are dropped through to the lower level. The accompanying illustrations indicate the procedure.

Fig. 1 gives a panoramic view of the molding unit on the upper level. To the left the molding equipment is located and to the right the pouring and subsequent operations take place. This shows a pouring deck consisting of a circular rotating table on which deck molds are placed and closed, the pouring following in sequence. On the farthest side the dumping of the sand is accomplished by means of a hoist removing the molds in sequence from the table.

Fig. 2 shows the relation of the molding equipment to the pouring equipment and indicates the plan diagrammatically. There will be noted on the right a circular table on which the molds are placed. This table is advanced automatically at the proper speed and is driven by an electric motor. The cross lines over the table indicate in the foreground the trolley track on which the molten metal is delivered and in the background showing the swivel beams over which the molds are delivered from the molding machines on to the pouring table.

In the extreme background there is indicated the dumping grate, dumping swivel hoist and the castings chute. To the left as indicated by the two circular areas are the cope and drag molding machines respectively. These are set over heavy steel grates so that any excess sand delivered to the molding machines drops through this grating to the lower level. Surrounding the two molding machines there is a gravity conveyor on which the flasks are placed at the point of dumping, permitting the return of these flasks to the molding machines.

To the extreme left there is indicated the sand slinger with the swivel sets so that the sand can be delivered to either molding machines. The upper left hand corner shows a bucket elevator and chute by means of which the sand is delivered from the lower

FIG. 1—PERSPECTIVE OF UPPER LEVEL OPERATIONS OF MOLDING AND POURING

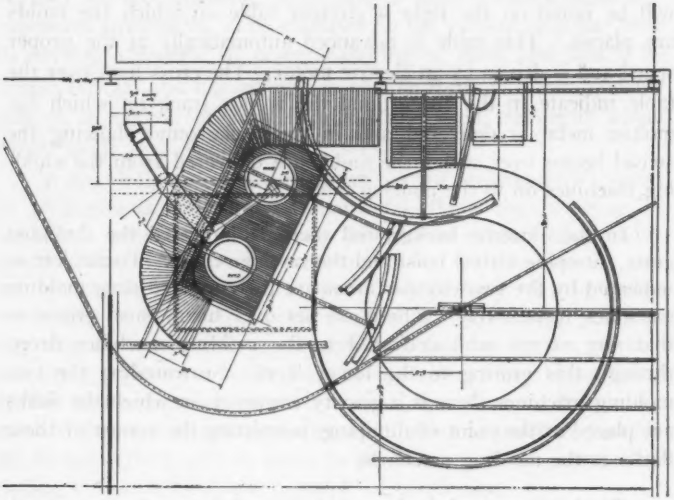

FIG. 2—PLAN OF UPPER LEVEL LAYOUT INDICATING SAND HANDLING EQUIPMENT, MOLDING MACHINES, AND POURING TRACKS

level on to the sand slinger. On the upper level, therefore, the sand is delivered through the bucket elevator down through an incline to the sand slinger; from the sand slinger alternately to the two molding machines. From the latter the sand in the molds is transferred to the revolving pouring table opposite and from the

FIG. 3—MOLDING EQUIPMENT SHOWING SAND DELIVERY CHUTE IN UPPER LEFT HAND CORNER

table after pouring the molds are transferred to the dumping grate from which the sand drops into the device on the lower level.

In Fig. 3 is shown in the upper left hand corner the chute from which the sand is delivered into the sand slinger hopper. As shown in the group the sand slinger and the molding machines set on the grate bars. To the right is shown half of the mold suspended, ready to be transferred to the pouring table. In the lower

FIG. 4—CLOSE-UP VIEW OF THE SAND AS IT IS POURED BY THE SLINGER INTO THE MOLD

FIG. 5—VIEW OF THE POURING TABLE AND MOLDS IN THE PROCESS OF CONSTRUCTION

right hand corner are cores ready to be placed on the pouring table. It is to be noted that the use of the grate bars stops any accumulation of sand about the molding machines.

Fig. 4 shows a close-up of the sand as it is poured from the slinger into the mold. The stream of sand is not visible in the photograph.

Fig. 5 shows in the foreground one side of the pouring table with some of the molds closed. To the right two of the drag parts of the molds are open and in the background there is shown a cope mold being lifted off from the molding machine and ready to be moved along the overhead rail to be placed over the adjacent drag mold. Of minor interest is the rake placed over the pouring table to the extreme right. This levels off the sand from the pouring table. No bottom boards are used in this arrangement. In the background to the right is shown the sand slinger filling a drag mold.

Fig. 1 shows the pouring operation of the molds on the pouring table. It is to be noted that the rate of travel of the pouring table is such that it does not interfere with the pouring from the ladle which is suspended on the trolley track carried by the building structure.

Sand Treating

On account of the location, it is rather difficult to photograph satisfactorily the apparatus on the lower level where the sand is handled and treated. Fig. 6 shows the principal apparatus for treating and handling the sand. This consists, as will be noted, of a structure containing a number of circular shelves superimposed one over the other. The sand from the dumping grate is permitted to drop into a shallow hopper from which, by means of a short belt conveyor, the sand is dumped into a rotary wire screen which is mounted directly over the top shelf of the sand carrier. The sand therefore is delivered directly to the top shelf. Also such sand as drops from the grate bars on which the molding machines are located, drops directly on the same shelf.

This multiple-shelf carrier is rotated on a fixed axis and is supported on a series of rollers placed in an outward circle. The

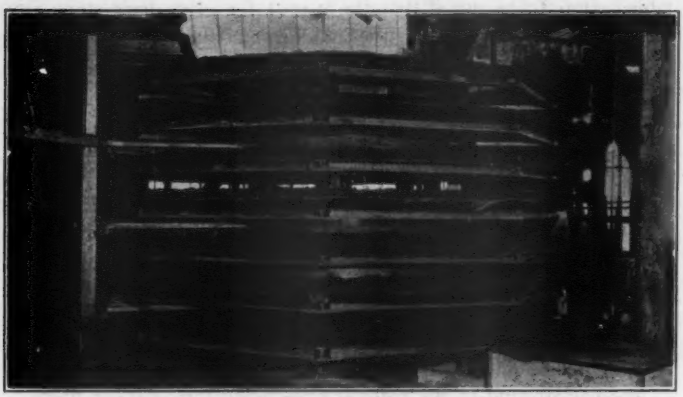

FIG. 6—REVOLVING SAND TREATING APPARATUS

FIG. 7—GROUPING OF EQUIPMENT ON THE LOWER LEVEL

lower shelf, as will be noted in the figure, has a circular rack through which the entire structure is driven by means of a motor and gear nest shown in the illustration in the foreground at the right under cover.

On each side of the structure it will be noted that there are extending arms between the shelves. These are mounted in a series of fixed shovels which are arranged so that as the load of sand keeps moving, a series of furrows are thrown over inward or outward as may be desired. On the upper shelf the shovels are so set that the furrows are thrown outwardly in succession until the sand drops on the extension of the shelf immediately below. The shovels over the second shelf are arranged to throw the furrows inwardly, and by means of an angular space toward the inner side, the sand is furrowed into the third shelf below. The third shelf has its shovels set to throw the furrows outwardly. Likewise the fifth and seventh shelves have their shovels set to throw the furrows outwardly. By this means the furrows alternately on the shelves are thrown inward and outward, until at the bottom they are raked off into a chute which leads to the boot of the sand elevator. This sand elevator and chute are located on the rear side and therefore invisible in the illustration.

A revised construction uses rotary arms in place of fixed shovels for turning the furrows on the shelves. This produces a more active and thorough cutting than the fixed shovels.

The tempering water is sprayed on the top shelf by means of a fixed perforated pipe controlled by a valve. In the process of turning the furrows, there being about ten furrows on each shelf, the sand is cut numerous times so that the mixing is extremely thorough, with the result that the moisture distribution is so well balanced and closely mixed with the sand that the penetration is complete in practically every part of the sand. "Tempering" is therefore quite complete although accomplished in a short time.

The aeration, as a result of the sand being exposed over a large area in the various shelves, and being turned over numerous times by means of the formation of new furrows constantly, is such as to cool the sand completely during the cycle of cutting. Fresh sand is fed into the system continuously by means of spout-

ing dry sand through a fixed aperture. This new sand is dropped on the top deck so that by the time the sand is cut over numerous times, the new sand is thoroughly mixed with the old sand. The condition of the sand by this means is maintained uniformly.

Fig. 7 shows the grouping of the equipment on the lower level, indicating on the left the sand carrier and on the right the inclined chute where the castings slide down to the lower level.

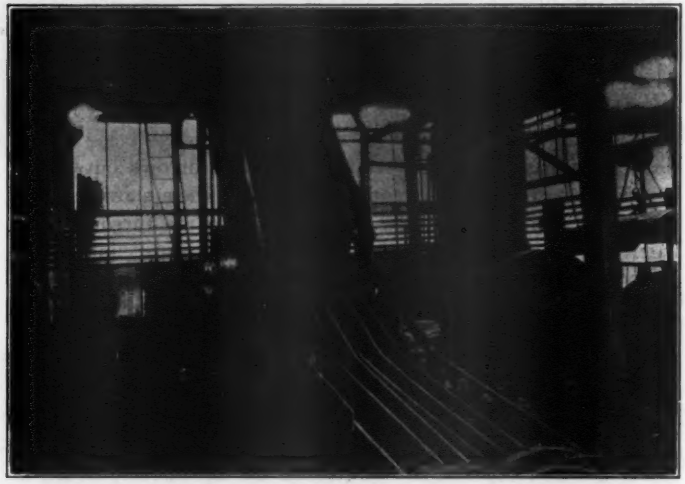

FIG. 8—ARRANGEMENT OF CASTING CHUTE AND MILLS

Fig. 8 shows a detail of the casting chute and the mills to the right which are loaded up directly from the chute also are shown the tumbling mill with the loads.

Equipment Increases Production

This sand handling equipment delivers daily in a period of nine hours over three hundreds tons of sand. This is done without any human labor and there is not a shovel around the place. The number of molds per man is four times greater by this

method than by the regular method. The number of molds produced by this unit is usually from 300 to 350 per day of nine hours. It is to be noted that with this unit all the operations begin and end practically simultaneously; that is, all of the men start to work at the same time and end their work at the same time. There is no attention given to the apparatus or sand during the night period. When operations cease, the motors driving the various equipment stop and all hands leave their jobs. The production per square feet of molding area, has, by this means, increased five times over the production with the previous standard methods employed.

The sand passes through a complete cycle every thirty minutes so that the sand is used over every thirfy minutes during the day. On account of the thorough cutting and mixing and on account of the uniform exposure, the sand is thoroughly fit to be used over in this short period of time. The sand is therefore in a continuously moving circuit. The sand slinger in this instance is not stopped and started as is usually done, but the stream is permitted to pour continuously, and the surplus of sand during the interim between molds is permitted to go down to the grating without interference.

Molds by this method are made so rapidly that defective molds are not repaired, but are permitted to go through the circuit without being poured. The making of a new mold is quicker than repairing molds.

Theory of Sand Preparation

The theory that may be advanced which makes the using of the sand possible with such frequency is that the distribution of moisture is so thorough that the capillary penetration is very short so that the time for penetration is reduced to a very short period. In the regulation manner of applying moisture to molding sand, some parts of the sand are wetted down very thoroughly while other parts are left to be rather dry, and with the regulation manner of cutting, not all of the sand is cut thoroughly so that to get equalization of moisture to the sand pile, it is necessary for the moisture to travel as much as several inches or more throughout

the pile. In this instance, it is likely that capillary action of moisture is limited to $\frac{1}{32}$ of an inch for thorough penetration; hence, such thorough equalization of moisture takes place within a very short time.

The sand carried on the carriers is usually about fifteen tons. The entire molding unit is located within an area of 27 feet by 36 feet. The speed of the pouring table as well as that of the sand carrier is regulated by variable speed motors. In practice, however, it is found that when these speeds are determined, there is very little need for changing them from day to day. The speed of the sand carrier is regulated in this instance by the capacity of the sand slinger to which it delivers about ten cubic feet per minute. Moisture is added to permit a 6 per cent total. The sand is tested several times a day for bond and the quantity of new sand adjusted accordingly. In regular production, there is very little need for changing the quantity of such sand.

It is to be noted that the number of filled molds during any one time is less than 5 per cent of the total production during the day and the sand that is in the mold accordingly is about 2 per cent of the total sand in the system. This rapid molding cycle permits the used of very few flasks and permits a ready change over of jobs without having to move any large quantity of flask equipment.

DISCUSSION

MR. RODGERS: In your method of the mechanical handling do you experience any balling up of the sand?

M. SKLOVSKY: I neglected to mention this, that balling up did take place, but we have found that instead of using six rakes or plows, we have put in, instead, rotary arms that are positively driven, and those are placed at such an angle that they bank the sand inward or outward on the shelf as desired, and since about a year ago we have had no experience at all with the balling up of sand. The balling up of sand, by the way, is increased by indiscriminate pouring on of water, and by a method of spraying the water in place of pouring it on with a hose or bucket, the balling up is practically eliminated.

MR. RODGERS: Do you experience any more balling up in a coarse grain of sand than a fine grain? I might say the Albany as against the Lumberton sand.

M. SKLOVSKY: I cannot answer you as to just what sand is being used now; perhaps Mr. Bancroft can. As I understand we use the same sand as on the rest of the job and we do not find there is any such experience as you relate, with the device we have now.

MR. RODGERS: I have found after a little experience in that line, that fine grained sand seems to ball up, sand that has, say, 40 per cent of silt, seems to ball up to a greater extent than the Lumberton, which has a small amount of silt.

P. T. BANCROFT: We have had some trouble in regard to the balling up originally, but after putting in these paddles we beat the sand up. We are burning the bond out so rapidly that it has been rather difficult for us to get a sand that would hold up our bond without increasing the volume in the system too much. We require pretty highly bonded sand and while we could get some sands that are highly enough bonded, they have not the openness and in order to get a sand open and high enough bonded, we are still feeling our way around and sampling different sands. When a sand gets too close I put silica sand in it and open it up. We test our sand daily in those systems as we do throughout the foundry and we do not have any trouble. Our percentage of good castings is very high on this system and by watching the sand you can always jockey and get by. To get an ideal sand that will give us the openness we desire and maintain our bond without increasing the volume in the system that is a rather hard sand to find.

M. SKLOVSKY: I just want to add one thing I left out, that is that we use no facing sand in this. The question came up early in the discussion as to the effect of reclamation on sand.

F. H. GULDNER: I would like to ask Mr. Sklovsky if he has any auxiliary devices in addition to these plows to mix up these sands other than the elevators and things of that nature, such as a Muller?

M. SKLOVSKY: Of course the elevators connected with this system do help to mix but we do not depend on those; we believe that without them the mixing is just as thorough; by the time the sand reaches the bottom of the revolving arms it is thoroughly mixed. This mulls it sufficiently. You see on each extension arm there are eight to ten of these revolving discs, and each one has about four arms and they revolve fast enough so that there is considerable mulling and a thorough mixing that does the job.

A MEMBER: Mr. Sklovsky says that the sand is cooled before it is tempered. Just how is that done when the sand is used over many times?

M. SKLOVSKY: The shelves are open all around and the layer of sand is only about three inches thick, and each time the paddle strikes it it throws it up in the air continually, so there is ample aeration, and by the time it gets down about two-thirds is good enough for cooling; excess cooling took place one time and we had to put canvas around to avoid excess cooling.

MR. THOMPSON: In regard to getting the moisture into the sand, do you put it in at one point of the passage of the sand or do you have different points?

M. SKLOVSKY: We add the moisture on the top shelf; everything is done at one point; there is a sprayer there and the fact that the stream is continuous all day long makes the amount of moisture required about uniform all day long. We add six per cent of moisture and it is maintained readily without attention, because a certain opening set for the day is all that is required, as the sand travels uniformly.

MR. THOMPSON: Then you find the sand comes with the proper degree of moisture?

M. SKLOVSKY: Yes, there is very little adjustment required on it.

P. T. BANCROFT: Different atmospheric conditions affect the amount of moisture you would have to put into the system, considering that you were putting the same number of molds up each day, the atmospheric condition will affect the sand appreciably. You have to watch it very closely; your moisture can vary quite a little bit if the openness of the sand is right and won't give you any trouble.

MR. THOMPSON: How much new sand do you add?

P. T. BANCROFT: We have a maximum of six tons a day, and there are 300 tons handled in the system; it is about the usual ratio of new sand to old per ton of castings.

MR. THOMPSON: Do you introduce that new sand at the point of shaking out?

P. T. BANCROFT: No, we introduce that on the top shelf; it mixes itself in going down through this machine.

Molding Sand Control in the Foundry

By H. W. Dietert* and W. M. Myler, Jr.,* Detroit, Mich.

Introduction

The care and skill required to make good castings with a low foundry loss is materially less when the molding sand used has a "feel" which tells the foundryman that his sand is particularly adapted for the job, than when the sand feels a little off. The ability of correlating the various "feels" of the sand with the various casting results is something which is to be gained only by years of experience. The principal reason for this is that there has heretofore not existed any specific language or terms whereby a foundryman might convey to his subordinates, or record for future reference, just what particular casting results a sand having a definite feeling would produce. This limitation placed the experienced foundryman in a group which might be almost termed a secret order, for he has a knowledge which he cannot convey to others readily. Under this system few real foundrymen are being developed in the modern foundry, where speed is such a vital factor, because of the great length of time required to gain the necessary experience.

Many different phases of foundry practices are at present being investigated. It is the purpose of this paper, however, to discuss only molding sand control.

The important physical properties of molding sand have been determined and given specific names, which will enable us to describe sand in common terms. Three of the most important of these are strength, moisture and permeability. The first two terms will undoubtedly be self-explanatory. The term permeability is used to express the openness or venting quality of a sand. Simple testing apparatus has been developed by which these properties or

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condition of molding sand may be measured and described in numerical values.

Foundrymen are capable of judging sand very closely but are not able to pass it on to their men. The tempering crew may be told that the sand is too dry or too wet, but no definite mark can be given them to shoot at. All they get is the continual supervision of the foundryman. A moisture test would release the foundry man from this work for then he could definitely ask for sand which would read between certain experimentally determined moisture limits. One bad result of the old system of describing moisture in sand is the fact that a molder will sometimes hesitate to report sand which he knows to be just a little too wet or too dry because of a fear that the sand wetter may carry the sand to the other extreme when trying to correct a small error.

In every foundry there are certain sand heaps which produce better results than others. There may be a man in the foundry who could add just the correct portion of new sand daily until the floors which were off would produce good results, but as a rule this man has gone so far up the ladder that his time is otherwise taken up. However, if there was a test sheet coming regularly to his desk showing openness, strength and moisture, he could then immediately guide his men to a low foundry loss without any undue effort. For each class of work he would show his men the best sand condition by linking up the practical results with the daily moisture, strength and permeability values. Instruction may be as follows: Machines 8, 9, 10 and 11 need sand which is tempered between 7 and 8, enough new sand added to keep bond up to strength readings between 2½ to 3 pounds and use the coarse, new sand when the permeability figures drop below 30 volumes of air.

We are all able to recall periods in our foundries when the casting loss was low, but few can show records which will show the condition of the sand at that time. A record of the sand properties as obtained by sand control work will in the majority of the cases show a marked difference of sand properties between low and high loss periods. Actual comparisons in foundries which have sand records show that every conceivable extreme sand con-

dition does exist. A saturation of heap sand with clay bond causes a high strength and low permeability, which results in a sensitive sand. Casting losses are high, due to poorly vented molds and finish is inferior.

Other cases have shown that sand has gradually become weaker until drops, swells and washes resulted. Conditions of the heap sand are not changed until castings are lost. The time to keep the sand up to a standard is when the results are excellent. Keep sand conditions constant or change conditions before trouble starts, then you are justified in claiming sand control.

Cores are frequently named the cause of blows when a dense sand, shown by a low permeability figure, was at fault. Moisture of molding sand may creep to the dry side, and trouble shows up in the cleaning room. The fault is laid to weak sand and immediately new sand is added in abundance. The sand becomes stronger than required. The molder has a new sand to work, which only invites losses. The real trouble with the sand that day was lack of moisture and not strength. A sand control sheet would have shown the moisture to be below normal. Conversely, the sand may be tempered to the extreme heavy side. Such sand does not lift off the pattern clean. The result is a rough casting finish, which is discovered probably the next day. Corrective measures are tried the next day, but we have that one lot of bad castings. Make every corrective measure before the castings are made by measuring the heap sand before a mold is made. Every sand heap should come up to definite specification before any molds are made from the sand. Save the castings before they are made. Your castings must come up to a specification, therefore, your sand should also come up to specifications.

For every type of casting there are certain sand properties which will allow the equipment, molding and iron requirements to vary within easy limits. When the sand is off, then the chance of losing the casting is materially increased. When we are able to maintain constant conditions in the foundry then we may expect constant loss. The foundry loss is directly proportional to the amount of indefinite conditions existing in the foundry. One of the greatest indefinite items existing in the foundry is heap sand condition.

The sand which the molders work should be the same every day for molding processes have become very mechanical. A mechanical operation is most efficient when operations are repetitions. Molding sand may be easily maintained at a definite condition by keeping the permeability, strength, moisture and fineness at some chosen values with the aid of sand testing. Every sand heap in the foundry requires individual attention. A heap of molding sand is not a heap of dirt, for dirt is something out of place. Molding sand belongs in the foundry and deserves utmost care in reconditioning to maintain a certain standard. This care of the sand does not become an extra burden when sand testing is incorporated with the work of the sand crew. The elimination of the uncertainty gives confidence to the organization, which is so essential to good foundry practice. This has been one of the most beneficial results derived from sand testing work as incorporated in all the foundries of the United States Radiator Corporation.

The manner in which this work was incorporated will be discussed in detail. The work may be divided into two parts; namely the control testing of the heap sand and the selection and checking of new sand. The control testing was first adopted in order to find out by practical comparisons just what the test values meant and what values were required for our work. With this in view, the control work will be discussed first.

1. *Control Testing of Heap Sand*

Sand Tester:—The type of man found to be the best adapted to test the sand has been an ambitious practical man out of our foundry crew; one who appreciates good molding sand and understands shop men.

In an eight hour day, one man is able to test all the molding sand for a 125 ton small casting foundry, calling for some 150 strength, moisture and permeability tests. The sand tester is one of the regular night men and is one of the sand crew. We have found no particular friction in establishing sand control. This is largely due to the fact that the work is made a man's work and its results are simple and definite.

Sand Testing Laboratory:—The apparatus required for testing the sand is located in the foundry foreman's office or an adjoining room. The foundry foreman uses the results of the sand testing, so he is placed in charge of the sand testing laboratory.

A view of a standard sand testing laboratory is shown in Fig. 1. The floor space required is equivalent to a room eight feet square. The testing machines are so arranged as to enable the sand tester to test the sand without unnecessary motions. The name and the use of each piece of apparatus is given below:

A.—Special built electric drying oven, 24 x 18 x 18 inches. Used for oven moisture test and drying new sand samples.

B.—Compression strength machine. Used to obtain strength of molding sand and of cores.

C.—Strength specimen rammer and mold. Used to ram sand samples for the compression strength test.

D.—Sand pan on rammer bench. Used as container for sand samples during test.

E.—Permeability machine. Used to determine the permeability.

F.—Permeability specimen rammer. Used to ram sand sample for compression moisture test and for the permeability machine.

G.—Balance. Two kilogram capacity with one gram rider. Used to weigh out definite weights of sand for compression moisture test.

H.—Dispensing tube. Used for measuring out exact amounts of water to temper test samples of new sand.

M.—Sample cans in tray. Used for carrying sand sample into laboratory.

The apparatus used for testing sand as shown in Fig. 1 is valued at $225.00. One sand testing laboratory of the group acts as a central sand testing laboratory, which makes the fineness test on sand grain samples received from each plant every month. This laboratory is equipped with a set of nine sieves and a sieve shaking machine for the fineness test.

The Time of Testing Sand:—The sand is wet down by hand and cut at night by means of automotive sand cutters. Each floor is wet down to the dry side and cut three times. A man called a sand temper then sprinkles the sand heap where needed as judged by feel and guidance received from moisture test figures.

The sand cutter then goes to an adjoining floor and starts cutting it. In the meantime the sand tester obtains three representative quart samples from the floor just cut. Samples are taken

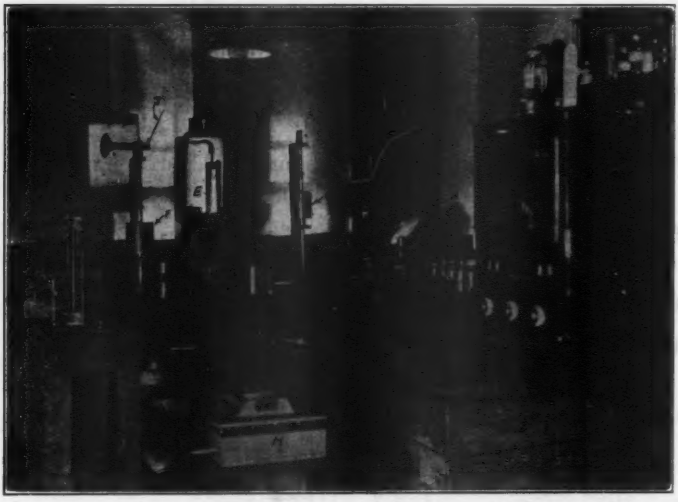

FIG. 1—UNITED STATES RADIATOR CORPORATION STANDARD SAND TESTING LABORATORY

one foot down into the heap at the front, center and rear sections of the floor. The samples are placed in three separate cans and carried in a screen bottom tray (M Fig. 1) into the sand testing laboratory, Fig. 1.

Testing Sand Samples:—The sand samples for the front section of the floor are emptied into the sand pan (D Fig. 1).

Moisture and Permeability:—The permeability specimen tube is filled with the sand and placed on the balance G. Sufficient sand

is taken out of the tube until balance comes to rest at 170 grams of sand. The tube with the sand is then placed under the permeability specimen rammer F. The sand in the tube is then rammed by dropping the 14 pound weight three times through a distance of 2 inches on the rammer rod stop collar. The moisture of the sample is read on the scale on top of the rammer by the following operation: Swing the indicating needle J over on the rammer rod and note where needle comes to rest on the scales. This needle does nothing more than indicate the length of the compressed sand specimen. If the sand is dry, then the needle will show a long specimen by remaining in the upper part of the scale. If the sand sample is wet, the needle will come to rest in the lower portion of the scale. Wet sand packs more closely than dry sand. This makes it possible to let each length of sand specimen designate a certain degree of temper or percentage of moisture. The sand tester records the moisture as indicated by the indicating needle.

His next operation is to obtain the permeability reading from the same specimen by attaching the tube I containing the sand specimen to the air pipe of the permeability machine E. He then turns the air valve to the open position and reads the pressure gauge. The pressure reading is converted to permeability or volume of air passed per minute by use of the table on the drum of the machine. This permeability reading is then recorded on the sand sheet.

Strength:—The strength of the sand sample is obtained by filling the mold shown adjacent to the strength specimen rammer C with sand from sand pan. He rams the sand in the mold with one drop of seven pound rammer, then strips the sand specimen free and places it in the strength machine B. He creates sufficient pressure on sand specimen to crush it by turning the oil screw plunger pump. The crushing pressure in pounds is recorded on sand sheet.

The three tests (moisture, permeability and strength) are repeated respectively on the remaining center and rear samples of the floor.

Sand Control Sheet

Every sand heap in the foundry is numbered and is referred to as floor number 10, for example. The moisture, permeability and strength readings for front, center and rear sections of every floor are recorded on the sand control sheet, Fig. 2. The control sheet is divided into two divisions; namely, the sand data space, which is filled out by the sand tester, and the finished casting part, which is used by the foundry foreman in checking results produced.

Form 0

UNITED STATES RADIATOR CORPORATION

SAND CONTROL TEST SHEET

PLANT Corry TESTED BY Sullivan DATE 8-20-25

SAND DATA (TO BE FILLED IN BY SAND TESTER)													FINISHED CASTINGS (TO BE FILLED IN BY FOUNDRY FOREMAN)		
FLOOR NO.	PERMEABILITY F	PERMEABILITY C	PERMEABILITY R	STRENGTH F	STRENGTH C	STRENGTH R	MOISTURE F	MOISTURE C	MOISTURE R	SACKS SEA COAL	BARROWS NEW SAND	REMARKS	PATTERN NO.	FINISH	REMARKS
2	40	40	40	31	30	31	6.4	6.4	6.3	1	1½	O.K.			
3	38	40	40	31	30	30	6.5	6.5	6.5	1	2	OK			
4	36	36	36	31	30	30	6.5	6.4	6.5	1	2	OK			
5	38	36	36	31	31	30	6.3	6.1	6.0	1	2	OK			
6	34	42	34	32	30	32	6.1	6.7	6.1	1	2	OK			
7	38	38	36	33	32	33	6.2	6.2	6.2	1	2	OK			
8	38	36	38	29	28	28	6.5	6.4	6.5	1	2	OK			
12	33	40	42	31	29	28	5.8	6.1	7.0	1	2	Front dry, Rear wet			
13	36	40	36	31	29	32	5.8	6.4	5.7	1	2	Front & rear dry			
14	36	40	44	31	30	31	5.1	6.4	6.5	1	2	Front dry			
15	34	38	38	33	31	31	6.2	6.4	6.5	1	2	OK			
16	33	36	36	33	32	32	6.3	6.5	6.5	1	2	OK			
17	34	31	31	30	34	33	6.3	5.8	5.8	1	2	OK			
18	34	34	34	31	32	30	5.9	5.8	6.1	1	2	OK			
21	33	34	31	34	34	33	6.1	6.1	5.9	1	2	OK			
22	36	34	34	30	31	32	6.2	7.0	6.1	1	2	OK			
25	40	40	34	31	29	33	6.5	6.5	5.7	1½	2	Exam.			
26	40	38	38	32	33	34	6.4	6.5	5.7	1½	2	OK			
27	38	35	34	32	31	34	6.4	6.3	5.9	1	2	OK			
30	34	38	38	34	33	33	6.1	6.4	6.4	1	2	OK			
31	38	36	38	29	31	30	6.5	6.4	6.4	1	2	OK			
32	42	40	40	28	29	28	6.7	6.4	6.5	1½	2	Exam.			

FIG. 2—SAND CONTROL TEST SHEET

The Use of Moisture Readings

The moisture readings are used by the night sand crew. The sand tester reports the moisture figures for each floor as soon as possible. It is possible to report the three moisture readings of a floor within three minutes. This allows the sand temper to add water or dry sand, if needed, to bring the moisture readings within

limits before the sand cutter finishes cutting the adjacent floor. The desired corrections are made and sand cutter makes its final cut on the tested floor. The sand tester checks floors which have been corrected. For illustration of moisture correction, we may choose floor No. 14, Fig. 2. The moisture reading for the front section read 5.1, center section 6.4, and the rear section 6.5. The sand tester marked this floor Exam. F. Moisture limits are 6 to 7 per cent. The sand temper is given these readings and he immediately knows that the front section is a little dryer than wanted, so he adds a little water to the front section of the floor No. 14. The amount of water that is needed to bring the front section moisture up to the range 6 to 7 is soon gained by experience. The foundry foreman glances over the moisture readings for each floor as recorded on sand control sheet the first thing in the morning. In this manner he gains a fair and rapid knowledge of the temper of every floor. During the day he may find that the sand on a certain number of floors should be worked a little dryer to improve results. That night he will ask for the sand on those floors to be tempered between 5.8 and 6.8 in place of the usual 6 to 7.

The loss of moisture in the heap sand varies as weather conditions change. During wet season, the sand is tempered nearer the lower limit and sand with moisture reading a fraction below lower limit is passed while during dry weather the upper limit is favored.

The Use of Permeability Readings

The permeability readings are probably the most popular of the three tests. The value of open sand is not questioned by foundrymen. The question as a rule is how close a sand can be safely worked. The greater the permeability for each class of work, the less care is required in tempering, ramming and gating. Again we have limits between which the permeability of the heap sand may safely vary for each class of castings. The lower limit of permeability for radiators was at 25, which gave freedom from venting losses without undue effort. An upper limit of 35 insures a sand with sufficient openess and yet produces no ill effects on casting finish. These limits are not so set as the moisture limits.

Variation in permeability readings may be out of the limits considerably and not cause any specific difficulty; however, the chances of having difficulty are increased. The larger the number of floors which are worked with a permeability lower than limit set for most desirable results, the more pronounced will this chance become.

The permeability of the heap sand governs the proportion of coarse to fine new sand addition. Under certain adverse conditions, core sand is added to the heap sand to increase the permeability.

The Use of the Strength Readings

The foundry foreman will be able by practical experience in a short time to connect his "feel" with the strength readings. This will enable him to determine definitely what strength of heap sand will give best results. A record of sand and casting result may be kept over an extended period without taxing his memory.

For radiator castings, a 2.5 to 3.2 pound heap sand has proven to give the best finish and lowest losses. Every floor running this class of work is kept within these strength limits by daily addition of new sand. Either the omission or addition of excess new sand may be readily detected by noting the control sheet. When a foundry operates with a non-varying sand of adaptable characteristics, then it is possible to run a low loss. Sand testing will not temper nor mold sand, but it will aid in maintaining definite conditions in the heap sand. This is only one of the essentials of the low loss combinations.

Sand Comparison Between Plants

Every foundryman knows the value of visiting other foundries in order to eliminate the isolation tendency by exchanging practices. A discussion always reveals our position and gives us a basis for comparison. The control of heap sand has suffered greatly due to an absence of a basis for comparison. To fill this want, all our plants receive each week a sand control comparison

sheet, Table 1, showing the average strength, permeability and moisture of each sand used for various classes of castings at each plant. This enables each plant to know the character of sand used by the other plants. Plants also receive every six weeks a duplicate copy of the other plants' sand control sheet, Fig. 2.

The value of exchanging the sand data among plants may be best proven by noting the remarkable close duplication of the heap sand used at each plant where the same class of work is made. For example, note the permeability column for Corry, Detroit, Dunkirk, Edwardsville and West Newton radiator sand. A study of this sheet shows proof to the most doubtful. Whenever a group of foundries running castings ranging in size from

Table 1

SAND COMPARISON SHEET SHOWING AVERAGE STRENGTH, PERMEABILITY AND MOISTURE OF HEAP SAND USED AT ALL PLANTS

	Permeability	Strength	Moisture
Corry	31.0	3.24	6.0
Detroit	24.5	3.2	6.6
Dunkirk	26.7	2.9	6.8
Edwardsville 4–23	35.1	2.54	6.9
Edwardsville 4–30	36.5	2.47	6.9
West Newton—Col	35.2	2.15	7.5
West Newton—Wall	30.3	2.5	8.5
Detroit Plate	24.0	3.36	4.56
Geneva Plate	28.5	3.1	9.3
Detroit Boilers	33.0	4.3	6.9
Geneva Boilers	38.0	3.1	7.3
Geneva Boilers (Pots)	59.7	2.7	7.4
Geneva Boilers (Bases)	42.0	2.3	7.4

a thousand pounds to plate work, agree on types of heap sand by test figures, then we can safely say that sand test figures do mean the same thing as the foundryman's "feel."

An additional point which may be mentioned is that, without sand testing, it would be next to impossible to get a group of foundries to agree on the same openness, bond and moisture of heap sand to use on any certain class of work. This agreement is only possible because sand testing is definite and each foundry came to the same definite conclusion by the comparison of their sand control sheets and their loss. These conclusions are that a definite permeability, strength and moisture on each class of work are essential to produce a first class finish and a low casting loss.

The first of each month every plant laboratory washes the clay bond out of a sample of sand from every class of heap sand used. The percentage of clay is determined by loss in weight. The cleaned sand grains are then placed in the permeability tube I, Fig. 1. A set of tight fitting screens form ends for the specimen. The sample is then rammed under the permeability rammer with the usual three drops. The permeability reading is next obtained, and is called the base permeability of the sand. It is called base permeability because it gives the openness of the sand grains or the backbone structure of the heap sand. This is the starting point governing permeability and compares all sand under like condition, namely, zero clay bond.

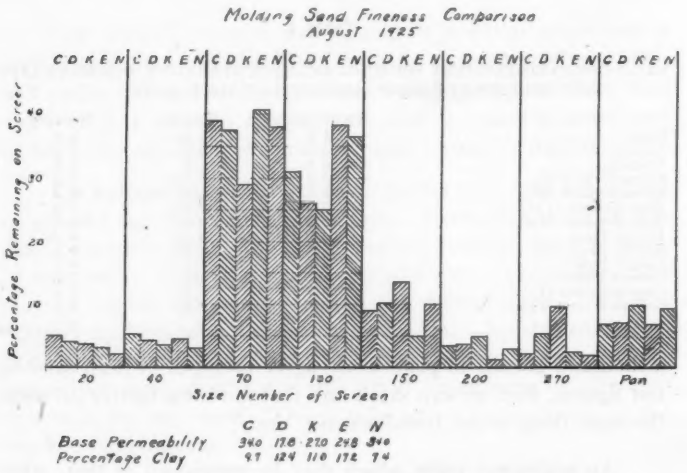

FIG. 3—FINENESS TEST COMPARISON SHEET

The sand grains, base permeability and percentage clay data are mailed to the central laboratory where the sand grains are placed in a set of nine screens. These screens are mechanically vibrated to distribute sand grains on screens which will retain them. The next operation is to express in percentage the amount of sand grains retained on each screen from coarse to fine.

The data, fineness, percentage clay and base permeability are compiled on Fineness Test Comparison Sheet, Fig. 3, and a copy is mailed to each plant. In this manner, each plant is able to know whether their sand is getting finer or coarser, also how their sand compares in fineness with sand used by other plants. For radiator sands the percentage limits of sand grains retained on the 70 mesh screen is between 30 and 40 per cent, on the 100 mesh screen between 25 and 30 per cent and on the pan less than 10 per cent.

Moisture Control by Metering Water

A standard line of product is made in our foundry and a particular job may remain in the sand of a floor over an extended period. The order of the various operations, molding, pouring, shaking out, and tempering, follow in a definite interval of time. The condition of sand changes very little due to the cycles of operations and uniformity of the addition of new sand and facing material. The new sand addition is governed by strength and permeability, while casting finish largely controls the amount of facing material added. The addition of water by estimation and the checking for moisture by test is at best a corrective method. A preventative method is certainly more to be desired. The metering of the water to temper a floor may possibly be classed as a preventative method.

At our West Newton plant, a 100 gallon clock dial meter is attached to the tempering hose to enable the sand wetter to place a definite quantity of water on each floor. The quantity of water for each floor was determined by trial. This method is proving very satisfactory and appeals to the foundry organization. The regular sand control testing is still carried on simultaneously with the metering process.

Conclusions

This outlines the general system of sand control as practiced in our plants. We have endeavored to show the method in which it is carried out and the types of condition we attempt to maintain. There has been no attempt made to give minute details either of apparatus, construction or operation. For those who care to in-

vestigate the details, there is appended a group of reports dealing with the construction of test apparatus and details of operation.

2. Tests on New Molding Sands

Selection of new molding sand:—The tests which may be made on new molding sands group themselves into two classes; namely, adaptability tests and quality tests. The adaptability tests are permeability, base permeability, strength, percentage clay and fineness. These tests show whether a sand is suitable for a particular class of work.

The quality tests are moisture working range, lime, gas volume, durability, and clay bake. These tests are used to determine whether a sand possesses properties such as long life and resistance to washing, and also whether a sand will be easy to temper.

Samples:—Prospective sands are chosen by their "feel." Gallon samples are then requested from the producer of the sands which seem desirable. Each sample received is placed in an air tight gallon can, correctly labeled and filed.

Permeability and strength test:—The strength and permeability of a sand increases as water is added to the sand until it becomes wet, in which state the strength and permeability decreases as the sand becomes wetter. This makes it necessary to test the strength and permeability of a new sand with various moisture contents to determine the maximum strength and permeability.

The first step in this test is to dry the new sand sample. Then weigh out a definite amount of sand; for example, 1000 grams (2.2 pounds). With the aid of a water measuring tube add definite percentages of moisture. Wet the sand to the dry side and determine the strength and permeability. Then add another per cent of water and repeat the tests. Continue adding moisture a per cent at a time and testing until the sand is too wet. Tabulate the strength and permeabilities with the percentage of moisure. Record maximum strength and permeability readings with the corresponding moisture on sand analysis sheet.

Fineness test:—The next tests are the percentage of clay determination, base permeability and sieve test. All of these are

commonly known as the fineness test, and the procedure is discussed in detail in report No. 6, "Fineness Test."

The percentage of clay as determined by this test enables one to determine definitely the amount of loam or clay contained in a sand and is of value in classifying sands.

The permeability test on certain sands, due to their balling tendency on tempering, gives a false reading. Certain high bonded sands are virtually opening sands when added to heap sands because the bond is scattered. Frequently these high bonded sands show a low permeability due to the excess clay closing up the void space. The grain structure of a sand will determine whether it will open or close a heap sand. The base permeability as determined in the fineness test actually obtains the venting quality of the sand grain structure and compares all sand on the same basis; namely, zero clay content. The base permeability is used to determine the effect of the new sand in the heap with reference to the permeability. The results of the sieve test as determined from the sand grains in the last part of the fineness test are used to determine whether the new sand contains a larger percentage of fine or coarse sand grains than found desirable by comparison of sands used in the foundry. The base permeability may be used to express the average fineness of a sand and is undoubtedly more suitable than the numerous mathematical expressions.

Moisture working range:—Certain molding sands have a property which make them easy to temper, while there are others that require extreme care in tempering. The latter type of sands is very sensitive to water and is called short moisture working range sand. The strength and permeability change rapidly with a small variation in moisture. The readings of the strength and permeability test are used to determine whether a sand has a short or a long moisture working range.

Durability test:—Tests are of the most practical value when they more nearly approach or duplicate actual conditions. A molding sand is said to have long life when it has the ability of regaining its molding properties by taking up moisture and retempering readily after it has been subjected to a severe drying process.

The durability test subject new sand to this condition. A tempered sample of the new sand is placed in a furnace at 600 degrees Fahr. for two hours and is then allowed to cool in the air. The sample is then retempered and left to stand for twelve hours. The strength and permeability are then determined. The loss in strength is expressed in percentage. A desirable sand is one in which the loss will not exceed 20 per cent.

Clay Bake:—The manner in which the clay bond in a sand bakes when the molten iron flows over the surface of the mold governs to a large extent whether the iron will wash the sand. There are sands which contain clay bond that dry firm upon baking while others have a bond which dries to a powder. In considering the life of a sand and its resistance to cutting, the manner in which the clay bond bakes is an important factor.

Lime.—The relative amount of lime is determined by the addition of hydrochloric acid to a small quantity of the sand in a test tube. Sands which bubble appreciably are rejected.

Gas Volume:—The amount of gas which a new molding sand will form upon heating is being investigated. The practical value of this test is not known at the present time.

Checking Shipments of Sand:—Every car of molding sand received is tested for strength and permeability. These test values are compared with those of the sample of sand furnished by the producer. Rejection of car lot shipments is not practiced, for a greater mutual gain may be obtained by co-operation. Should shipments test low in strength, the sand producer is advised of the exact condition, thus enabling him to correct conditions on future cars. In case sand tests low in permeability, an opener sand is requested in future shipments. This procedure is definite and finds the variation from the desired sand before the condition becomes serious. The manner in which each car is tested is discussed in detail in report No. 13, "Checking Car Lot Shipments of Molding Sand."

APPENDIX—MOLDING SAND CONTROL IN THE FOUNDRY

Report No. 6.—Fineness Test and Base Permeability of Molding Sand

Object

The introduction of fineness test and base permeability in the selection and plant control test of molding sands.

The fineness test of molding sand shows the percentage of sand grains retained on each screen of a series of ten screens. Grain sizes and distribution of sand grains are determined by knowing the percentages of sand grains remaining on each screen. The amount of objectionable grain sizes, as pan material, which is exceedingly fine, and the large poor crystalline grains are also definitely indicated. The permeability of a sand in its natural form shows its ability to pass gases. The amount of clay substance contained in the sand will materially affect the permeability of the sand. Thus a reduction of the clay content of the sand will change the permeability of the sand. Whenever a new high bonded molding sand is added to the heap sand a large portion of the new clay bond is taken up by the heap sand, which will increase the permeability of the new sand. In this way a comparatively dense high bonded sand may become a much more open sand by the reduction of its clay content.

If the natural permeability is only considered in the selection of sand, the low bonded molding sand will show a higher permeability as a rule than the high bonded molding sands. In other words, suppose we determined the permeability of a high and of a low bonded molding sand, the test may show that the low bonded sand is the more permeable. Should the clay substance in a high bonded molding sand be reduced to the same percentage as that of of the low bonded molding sand, then it is possible that the permeability of the high bonded sand would be the greater. A molding sand may be inherently dense due to its grain size distribution or to a larger percentage of exceedingly fine material which will be retained on a 270 screen or on the pan. In some sands the percentage of pan material is as high as 20 per cent. The permeability of

the grain structure is the controlling factor of the permeability of the sand. The clay content of the heap sand is always maintained within a somewhat reasonable limit. The variation of the clay substance in the heap sand will cause an increase or decrease of permeability above or below the permeability of the grain structure of the heap sand. Thus it may be seen how important it is to have the base or grain structure of a sand with a desirable permeability. The permeability or grain structure without the clay will be called the base permeability.

Machine

The apparatus required to make the various tests and base permeability determinations are as follows:

4:—1-quart large mouth bottles.

1:—2-foot length of ¼-inch rubber tubing.

1:—Screen shaking machine.

1:—Permeability test specimen rammer.

1:—Permeability apparatus.

1:—2-inch specimen container equipped with circular retaining screens.

1:—Set screen.

Screen No.	Opening in Inches
6	.132
12	.066
20	.033
40	.0165
70	.0083
100	.0059
150	.0041
200	.0029
270	.0021
Pan	

Material

Caustic Soda.

Method.

Approximately 500 grams of sand to be tested is placed in an oven and dried for a period of one hour at 212 degrees Fahr. with a tolerance of 5 degrees. A 300 gram sample of the dry sand is then placed in a quart bottle. A sufficient amount of caustic soda solution is then added to completely wet the sand in the bottle. The bottle is then filled with water, after which procedure the sand in the bottle is agitated by up-ending the bottle by hand or by a machine. The clay subsance contained in the sand is torn apart by the caustic soda, which makes it possible for the clay to be in colloidal suspension.

The sand grains are freed from the clay bond in a similar manner as soap will remove grease from a person's hand. The bottle containing the sand sample is let stand for a period of ten minutes in order that the fine sand grains may settle. The water containing the clay is syphoned out with a rubber tubing. The end of this rubber tubing is held one inch from the level of the sand grains in the bottle. The water is repeatedly added and syphoned off at five minute intervals until the water becomes clear. The sand grains are then dried and weighed.

The loss in weight is the amount of clay substance contained in the sand. A sufficient amount of sand grains are then placed in a permeability sand specimen container to make a rammed sand specimen with a length of two inches. The sand specimen is rammed by a ramming force of three blows of a 14-pound weight dropping two inches. The dry sand is held in position in the specimen container by means of placing old screens on each end. The container is next attached to the permeability apparatus and the amount of air flowing through the specimen is determined, thus obtaining the base permeability of the sand. A 100 gram sample of the sand grains is then placed on the top screen of the screen set, which are stacked one on the other. The screens are then placed in a shaking machine, preferably of the Ro-Tap design This machine shakes the screens in a circular plane and taps them

on the top. After shaking the screens for a period of one-half hour the amount of sand grains retained on each screen is then weighed and expressed in percentage.

Results

In Table 2 are tabulated test values of the characteristics of various sands showing the effect of clay substance and grain structure on the permeability of molding sands. It may be noted that the maximum permeability of the No. 3 boiler heap sand (Detroit plant) is 37, and after the 16.7 per cent of clay

Table 2

COMPARATIVE TEST VALUES OF SAND SHOWING EFFECT OF CLAY AND GRAIN STRUCTURE ON THE PERMEABILITY

Characteristics	No. 3 Boiler Heap Sand-Detroit	No. 3 Sand H. H.	Worden Pit	No. 7 Zanesville Sand—West Newton Plant	No. 4 Brandon Sand
Max. Strength.....	3.0	8.0	3.0	13.5	5.25
Max. Permeability.	37.0	2.5	21.0	22.0	6.5
Base Permeability..	42.0	10.0	24.5	31.5	1.0
Percentage Clay...	16.7	43.0	15.0	40.0	16.4
Fineness Test					
6	0.7				
12	3.4				0.8
20	10.9	0.1	0.5	1.0	4.7
40	12.3	1.20	2.2	1.4	12.3
70	32.1	39.0	12.7	14.1	19.8
100	22.0	22.60	24.9	41.0	15.6
150	10.2	6.60	26.8	28.5	12.9
200	2.0	1.60	9.0	5.8	4.0
270	4.8	5.6	15.0	7.2	10.3
Pan	1.9	24.7	11.8	4.0	20.0

substance is removed, the base permeability of 42, is obtained or an increase of 5 c. c. The fineness test shows that the grain sizes of this sand are distributed over a very large range. The amount of pan material of 1.9 per cent is exceedingly low. To increase the permeability of this sand the grain structure of the sand must be broken up by the addition of a very uniform new sand consisting of approximately No. 40 sand grains.

The H. & H. sand showed a maximum permeability of 2½. Its base permeability is 10, showing that the high clay content of 43 per cent closes up this sand to one-fourth of its base value. The fineness test shows that the sand contains 24.7 per cent of pan material, which is an excessive amount. This sand would be a very open sand provided it did not contain this fine pan material. The pan material not only closes the sand but will float in molten iron should the sand become weak.

The permeability of the Worden pit sand is a little affected by removal of the clay substance. The fineness test shows that the sand contains 15 per cent of No. 270 screen and 11.8 per cent of pan material. This quantity of fine material limits the permeability of the sand and also causes dirty castings provided the heap sand becomes weak.

The No. 7 Zanesville sand as used at the West Newton plant has a maximum permeability of 22 and a base permeability of 31½, showing an increase of 9½ c. c. after the 40 per cent of clay substance was removed. The grain size distribution of this sand is very good. The base of this sand consists of sand grains retained on the No. 100 screen. The grouping of the grain sizes one below and one above the base is also desirable. The amount of fine material in this sand is just sufficient to give the sand a comparatively good texture.

A comparison of the maximum permeability of the Worden pit and No. 7 Zanesville sands would indicate that both of these sands are of the same openness. However, the base permeability shows definitely that the No. 7 Zanesville sand is the more permeable. The base permeability is the more practical criterion in this case because the clay substance in the No. 7 sand would be materially reduced when mixed in the heaps.

A sand which has a lower base permeability than its natural maximum permeability is the No. 4 Brandon sand. Its maximum permeability is 6½ while its base permeability is 1.0. In this case the clay substance is just sufficient to coat each sand grain, and does not fill up voids. An examination of the fineness test will show that 10.3 per cent of the sand was retained on the 270 screen and 20 per cent on the pan. This makes a total of 30.3 per cent of fine material, which gives this sand a very dense grain structure. The wide distribution of grain sizes also helps to close up this sand.

Conclusions

The determination of the base permeability and fineness test makes it practical to determine why a molding sand has a permeability of a certain value and also how its permeability may be changed. The fineness test shows the exact amount of clay sub-

stance contained in the sand and also the distribution of the grain sizes. Considerable advancement may be made by a further study and application of these properties of a molding sand to shop practice and results obtained in the plants from various molding sands.

Fineness Test

Procedure

For Percentage Clay

1. Obtain a representative sample of heap sand not less than 500 grams.
2. Dry sample of sand in oven at 212 degrees Fahr. for 1 hour.
3. Cool sample and weigh out a 300 gram sample. Do not pour sand to obtain this sample—use the scoop.
4. Place the 300 gram sample in a 2 quart jar.
5. Add approximately 250 c. c. of 1 per cent sodium hydroxide solution. Note: This solution is made by measuring out 1000 c. c. of water with the 500 c. c. flask. Then add 10 grams of sodium hydroxide to the 1000 c. c. of water, i. e. 10/1000 = 1 per cent.
6. Fill the jar containing the sand sample with water within 2 inches from the top.
7. Clamp top on jar and shake violently for five minutes.
8. Hold jar still for a minute. Then shake jar sufficiently to wash sand grains off the jar cap. Next remove cap.
9. Let stand for 10 minutes.
10. Fill the rubber tube with water. Pinch one end and insert other end into the jar until one inch from sand grain level.
11. Release the pinched end of tube and syphon out water to 1 inch above sand grain level.
12. Fill jar with water. Let water stream stir sand grains.
13. Syphon after 5 minutes standing.
14. Repeat operations 12 and 13 until the water is clear after 5 minutes standing.
15. Then fill jar half full of water.

16. Hold hand over top of jar and upend jar over a drying pan. Remove hand to allow sand to run into pan. Rinse all the sand grains into the pan.
17. Let stand for 5 minutes.
18. Pour off all the water possible without loss of silt.
19. Dry in oven at 212 degrees Fahr. for 1 hour.
20. Weigh sand grains.
21. Express loss in weight in percentage of clay. Example: Weight of sand grains, operation 20 as 240 grams 300 — 240 = 60 grams clay. Per cent clay = 60/300 = 20 per cent.

For Base Permeability

22. Place screen in permeability specimen retainer.
23. Scoop a sufficient amount of sand grains in specimen retainer to give approximately a 2 inch specimen.
24. Place screen on top of sand grains.
25. Ram with 3 drops and obtain permeability. This gives base permeability.
26. Mail sand grains to Detroit plant for screen test. Send report on per cent play and base permeability to Operating Department.

For Screen Test—(Detroit Plant)

27. Assemble the screen on bottom pan in order of fineness.
28. Place a 50 gram sample in the top screen. Use scoop in taking this sample and mix well.
29. Place screens in Ro-Tap and shake for 30 minutes.
30. Weigh the amount of sand grains retained on each screen. Since a 50 gram sample is used, multiply weight in grams retained on each screen by two and express fineness in percentage.
31. Record data on form No. 315 (Fig. 8).
32. Mail data to operating department.

Report No. 8—Strength Testing Apparatus and Test Procedure

Introduction

The strength test is used to obtain numerical values showing the comparative bonding qualities of molding sand which deter-

mines its ability to hold together. This ability of molding sand to hold together is called the strength of the sand. The A. F. A. Sub-Committee on Molding Sand Test called the strength of molding sand "'cohesiveness" or "Bond." The word strength is preferred due to its simplicity and its present day use in testing other materials, for example, cast iron.

The A. F. A. cohesiveness test employs a molded bar of molding sand 16¾ inches long with a cross section of 1 by 2 inches. This bar of sand is pulled over an edge until the projecting end breaks off. The portion of the bar which breaks off is weighed in grams. The number of grams is used to designate the cohesiveness or strength of the sand. This method of testing the strength of molding sand is not recommended for our plants sand control due to the length of time required to make the test. The strength test as outlined in this report is the most rapid method devised up to the present time and is also the most accurate and simple test known.

The bonding quality or strength in molding sand whether it be of heap sand or new sand is one of the most important physical properties. A slight change in the bond of either new sand as shipped or of heap sand may readily be determined by the strength test. Heap sand does not become weak over a single cast but the decrease of strength is gradual. A glance at the strength reading will immediately show the foundrymen whether the heap is loosing some of its bond. The result is that all the heaps may be kept up to a standard requirement, thus materially reducing the chance of casting loss.

The strength machine is so designed that a rammed specimen of sand is loaded with an oil pressure. The stronger the sand the larger the amount of oil pressure required to crush the sand specimen. The amount of the oil pressure is determined by the reading of a pressure gauge. Thus the strength of the sand is expressed as two or three pounds as the case may be. The two-pound sand will hold up two pounds per square inch of sand surface.

Construction of Apparatus

The rammer for the strength specimen is constructed in accordance with a detailed drawing as shown in Fig. 4. It consists of a steel rod supported by a steel frame. The guides of this steel frame are drilled to give the steel rod a sliding fit. A cast

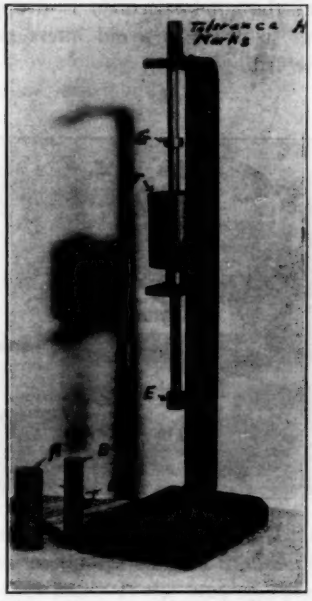

FIG. 4—STRENGTH RAMMER WITH MOLD AND BOTTOM RAMMER

iron head weighing exactly seven pounds, slides on the rod. Stops pinned to the steel rod regulate the movement of this head to 2.56 inches.

A mold and a bottom rammer are shown in Fig. 4. The mold for the sand specimen is made of bronze or brass. The bottom rammer is made of steel.

In Fig. 5 is shown the strength testing machine. The base and hand wheel of machine is made of cast iron while the remaining parts of the machine are constructed of steel.

The strength machine consists of a screw plunger mechanism on one end while on the opposite end is a freely lapped piston. This piston should be ground in until a film of oil separates the piston from the body of the machine. A cloth screen is placed around the piston to protect it from the sand. The screw plunger mechanism is used to create an oil pressure. The projecting end of the base under the sand specimen is dropped lower on the late built machines in order to avoid interference of sand as it accumulates on the arm.

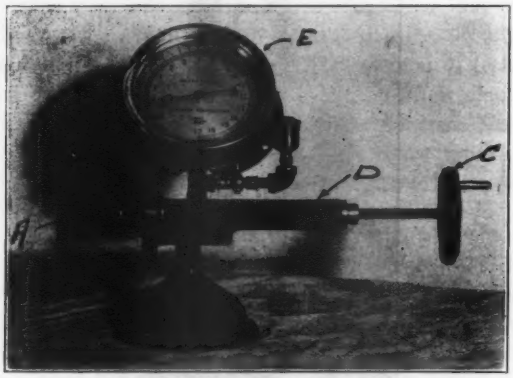

FIG. 5—STRENGTH TESTING MACHINE

The method of attaching the pressure gauge and oil reservoir is shown in Fig. 5. The pressure gauge is recalibrated to read one quarter of its original readings. This is readily accomplished by making a new dial of drawing paper.

Preparation of Sample

The sample to be tested should be an average one representative of the heap sand, car lot, bank, or whatever source it is taken from. The amount of moisture in the sand influences its strength. Thus the strength reading of the heap sand is affected not only by the amount of bonding substance contained in the sand but

also by the amount of moisture with which it is tempered. New sands should be tempered to the dry side and then strength readings taken after each addition of 1 per cent moisture.

To check sand received in car lots the representative sample should be dried in an oven at 212 degrees Fahr. with a tolerance plus or minus 5 degrees. After this sample has cooled the sample is tempered with sufficient amount of water to bring its moisture percentage to that shown on the permeability curve which will give the sand its maximum permeability.

Ramming

The sand specimen is rammed by means of a ramming apparatus as shown in Fig. 4. The mold A is set over the bottom rammer B_1 the stop pin C is used to hold the mold A in position on the bottom rammer B. Take a sufficient amount of sand to fill the mold. The mold assembly is then placed under the rammer E. The next operation is to let the rammer assembly rest on the sand in the mold. Remove the stop pin C, Fig. 4. This allows the lower end of the sand specimen to be rammed with the same force as the upper end of the specimen. The ramming weight F is next raised to the upper stop G (2.56 inches) and let fall. One drop of this weight is required. This gives the specimen the same hardness as the permeability specimen. Note whether the upper end of the rod is within the tolerance marks H; if not discard the sample. Should the rod project above the tolerance marks, place the stop pin Z in lower hole. If the sand specimen is short, which would be indicated by the ramming rod falling below the tolerance mark, the stop pin C is placed in a hole above the original position. In control work the operator will soon determine which hole gives him a sand specimen of the required length.

Removing sand specimen from mold

The mold assembly is placed on one side of the rammer base as shown in Fig. 4. Grasp the mold with the right hand and press the mold down. This operation strips the sand specimen free from the mold. Grasp the specimen by the thumb and the index finger of the left hand and blow off each end.

Operation of strength test

Retain this manner of grip on the sand specimen, A, Fig. 5, and place it in the strength machine as noted in Fig. 5. The hand wheel C of the oil pump is then turned at the rate of 120 R. P. M. until the specimen breaks. The turning of this hand wheel drives the plunger into the cylinder D, compressing the oil into the system. The oil pressure supported by the sand specimen is registered by the pressure gauge E. The maximum reading of the gauge, or the crushing strength of the sand, is recorded as the "strength." A single reading is sufficient to determine the strength of a heap sand provided the operator is experienced. However, for a new sand it is desirable to make at least three readings and record the average as the strength value.

Filling apparatus with oil

The cylinder D, Fig. 5, is filled with oil by screwing the plunger C in as far as possible without creating an oil pressure on the pressure gauge. Next open the cock G and fill the cup F with 600 W oil. Unscrew the plunger C in order that the oil will be drawn into the cylinder D. Close the cock G.

Calculations

The area of the piston head B, Fig. 5, is one-quarter of a square inch. Thus every pound per square inch in the system exerts on the piston head, Fig. 5, only one quarter of a pound. This pressure is supported by the sand specimen "A." The area of the sand specimen A is one square inch so that every pound per square inch in the system D exerts one quarter of a pound per square inch on the sand specimen. In other words, a pressure of four pounds per square inch in the oil system of the strength machine exerts a load of one pound per square inch on the sand specimen. Should a standard gauge be used, its readings must be divided by four to give pounds per square inch strength of the sand. To avoid this division a new dial is placed on the gauge with calibrations reading to one fourth of the original readings. The testing machines as installed in our sand laboratories are equipped with re-calibrated gauges and the strength is designated in pounds per square inch by the exact gauge readings.

Report No. 10—Compression Moisture Test

Introduction

The percentage of moisture in molding sand may be determined by a number of different methods. The methods may be divided into two classes, namely, direct and indirect moisture determinations. The direct moisture determinations are the most accurate while the indirect determinations are the most rapid.

The methods belonging to the direct moisture determination class are gravimetric and chemical methods. Under the indirect moisture determination class may be listed volumetric, specific gravity, compression and saturation methods.

Direct moisture determinations

The gravimetric method which employs a drying oven to evaporate the moisture in the sand is undoubtedly the most widely used at the present time, and it is also the most accurate method. By this method the moisture in molding sand is determined by expressing in percentage the loss in weight of a weighed sample of molding sand upon drying it in an oven at 212 degrees Fahr. The gravimetric method may be sub-divided into two sub-divisions, namely, ventlated and unventilated drying, and manual and calculated weighing. The combination of ventilated drying and calculated weighing is the most rapid method of these sub-divisions.

The chemical method of determining the moisture in molding sand may be divided into determinations involving temperature, pressure and concentration. The concentration chemical method involving the mass action proves to be the most reliable, economical and most rapid of the chemical methods.

Indirect moisture determinations

The volumetric method employs the change of the total volume of a weighed sample of sand as the percentage of moisture varies. A dry sample of sand will displace a smaller amount of water than a wet sample of sand. Water displacement is thus proportional to moisture in sand. This method is affected by the spe-

cific gravity of sand. For control work where the same sand is used each day, the change in specific gravity does not present a serious problem; for new sand the specific gravity of the sand must be first determined before a moisture determination may be made by the volumetric method. The advantages of the volu-

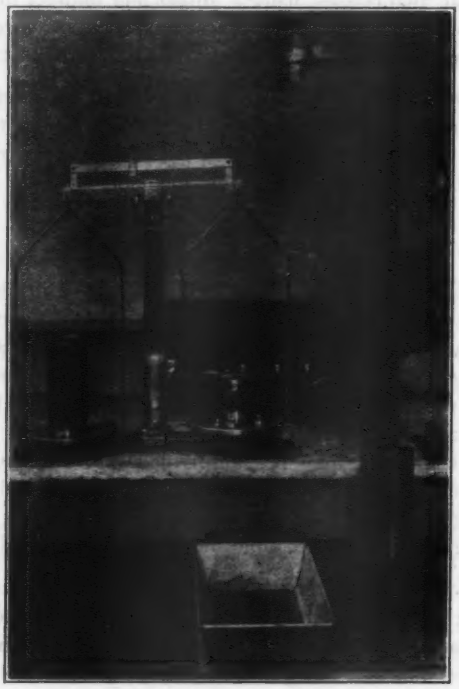

FIG. 6—COMPRESSION MOISTURE INDICATOR ATTACHED TO PERMEABILITY RAMMER

metric method are rapidity and large representative sample of sand which may be used.

Moisture in sand may also be determined by submersion of a weighed sample of sand in water to cancel the weight of moisture in the sand. This method involves the specific gravity and also certain mechanical difficulties.

The saturation method presents a number of very interesting physical properties. These new properties found by use of this test and method employed to make this test will be discussed in a later report.

The determination of moisture in molding sand by the compression method has proven to be the most rapid of all the methods devised so far. While its accuracy is not as great as some of the other methods discussed, it does possess a degree of accuracy which is sufficient for control work. The tempering crew in a foundry may temper sand with ease to a variation increment of 1 per cent variation, for example, from 6 to 7 per cent moisture content.

To work sand with less variation is not necessary providing sand is correctly chosen. A moisture determination method which will give readings that do not vary more than .2 or .3 from the correct readings is considered accurate enough for control work.

The compression moisture method meets these requirements and it is also the most rapid and most simple of all the methods.

Testing equipment

Laboratory Balance
Permeability Apparatus
Permeability—Specimen tube
Specimen tube pedestal
Permeability rammer
Compression moisture indicator

Construction of apparatus

The moisture indicator which is attached to the permeability rammer is constructed in accordance with detail drawing making the apparatus shown at A, C. D, Fig. 6.

The indicator consists of a brass frame on which is pivoted a needle with a knife edged bearing point $1\frac{1}{16}$ inch from the center.

The moisture indicator is attached to the top of the permeability rammer as shown in Fig. 6.

Principle of Operation

The length of a rammed sand specimen is directly proportional to the weight of sand and to the temper of the sand and moisture content. When a definite weight of sand is used for each ramming then the length of specimen will vary directly as the moisture content. The moisture of molding sand may then be determined by ramming up equal weights of sand and then determining the length of a rammed sand specimen. The moisture indicator which is attached to the permeability rammer is merely an indicating needle which registers the length of the rammed permeability specimen in the tube B, Fig. 6. The wetter the sand the shorter will be the sand specimen and the lower will be the rammer rod, allowing the indicating needle C to register lower on the scale. In place of graduating scale D of the moisture indicator in inches of the sand specimen length it is calibrated to read in corresponding moisture content of the sand.

Operation of Test

Secure a representative sample of sand from the sand heap and place 170 grams of the sand in a permeability specimen tube B. Place the tube with the weighed amount of sand under the rammer and then ram the specimen with three drops of the rammer head. Next, bring indicating needle over on the rammer rod and read percentage of moisture as registered by the needle C on the scale D. The specimen may then be removed and used for the permeability test. Care should be exercised in keeping the base plate of the rammer free from sand.

Calibration of Apparatus

The moisture indicator is calibrated by obtaining a number of heap sand samples. These samples should be of different degrees of temper, providing a wide moisture range may not be obtained from the heap. Slightly reduce moisture in some of the samples by drying and in some of the other samples increase moisture content by adding water. Place each sample in an airtight container and number the samples numerically. Obtain percentage of moisture for each sample by the oven method. Next make a compression moisture test on sample No. 1. Suppose by the oven

method sample No. 1 contained 3.1 per cent moisture, then the point where the indicating needle rests for sample No. 1 is 3.1. Mark this position on scale D as 3.1. Continue the above procedure until the readings are obtained throughout the whole moisture range.

It is not necessary to calibrate the moisture indicator for each kind of sand used in the foundry. While the indicator will not read the correct percentage of moisture of sand for which it is not calibrated for, it will give the relative variation of moisture. The instrument that will give the relative variation of moisture in molding sand will give the foundry organization figures by which to control the moisture in all the heaps. For example: Certain heaps are required to read 6 to 7 on the indicator while other heaps may require 7½ to 8½.

Conclusion

The compression moisture test is accurate enough to eliminate all poorly tempered sand. This moisture test in principle, manipulation or application may be easily mastered by a foundryman. Its use in a foundry has shown that it is a practical apparatus which may be used to produce practical results.

Report No. 13—Checking Car-lot Shipments of Molding Sand

Introduction

The quality of raw material used in the foundry will have much to do with the class of work produced. The consistency of the quality of the raw material governs, to a marked extent, the consistency of the foundry efficiency.

A low loss foundry may generally be classed as one where the chain of the various operations is executed to a definite repetition. A change of raw material either in origin or quality will unbalance the stability until the organization learns by experience just how the new material should be worked to produce results which are suitable to interlink with the operation chain of the foundry.

The supervision required to operate on a low loss is diminished when shipments meet a certain specification. The raw material which has varied the most and also has been accepted with the least amount of inspection is molding sand. Records showing the uniformity of sand shipments are certainly desirable. The

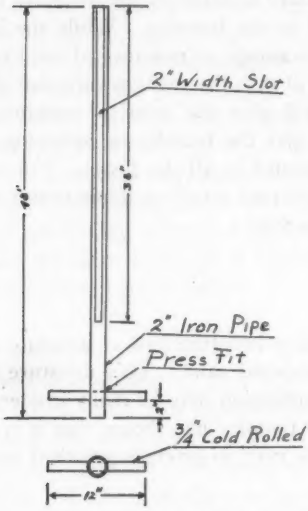

FIG. 7—DETAILS OF SAND SAMPLER

management may then definitely know the strength and permeability of each carlot of sand received.

The object of this report is to outline a standard method of checking sand shipments.

Equipment

1. Sand Sampler
2. Water bath heater or electric oven
3. Water measuring tube
4. Balance
5. Permeability rammer and machine
6. Strength rammer and machine.

Material

Representative sample from car of sand.

Test Proceduce

1. Sampling.—Sampling is an age old problem and remains to this day a problem to study.

A sampling method will not insure a representative sample unless the party sampling will place interest in his task.

The sampling method used to secure a representative sample from a carlot of sand shall be as follows: The sand sampler, Fig.

F 315-1M-7-25 UNITED STATES RADIATOR CORPORATION
SAND ANALYSIS REPORT

Sand 6 G Car No. Sample Plant Lab.
Shipper Buckeye Sand Co. Shipping Point Conneaut Date 4/13/25

		Fineness Test		Moisture	Perm.	Strength
Permeability Moisture	128 @ 9%					
Strength Moisture	4.4 @ 9%	6	1.0	5		
Base Permeability	219	12	12.7	6	67	2.3
Percentage Clay	9.1	30	41.0	7	77	4.0
Clay Bake	Medium	40	11.2	8	102	4.5
Gas Volume		70	7.2	9	128	4.4
Lime	O.K.	100	7.6	10	219	3.6
Heat Test 600° Fah.		150	5.5	11	300	3.6
% Strength Loss 16.2		200	1.6	12	326	4.2
% Permeability Loss 4.6		270	3.0	13		
Moisture Range Fair		Pan	7.8	14		
Tested by				15		

FIG. 8—SAND ANALYSIS REPORT INDEX FILE CARD—INFORMATION GIVEN ON REVERSE SIDE: LOW STRENGTH, OPEN BOILER SAND, SAND GRAINS BREAK UP IN HEAP

7, is pushed into the front end of the car and withdrawn. The sand in the sample is then pushed out to form a pile. Continue obtaining samples of the sand in the car every four feet by this method and piling the samples in a single pile. Mix and quarter this pile and take enough handfuls from each quarter to make a quart sample of sand. Mark car number and name of sand on sample.

2. Drying Sample.—Place the quart sample of the sand in water bath heater or electric oven (212 degrees Fahr.) and heat for two hours. Let sand cool.

3. Tempering.—Crush lumps in the sand. Then scoop 500 grams of sand into a pan on the balance. Empty the 500 grams of sand into the large sand pan. Fill the water measuring tube with water to the zero mark and then add the required c. c. of water to the sand. The required number of c. c. for the various sands are recorded on the sand specification card. For example: No. 2 Hatch Sand add 45 c. c. of water. No. 4 Mills Open add 50 c. c. of water. (Note: A set of sand specification cards should be located in sand laboratory for the sand testers.)

After the water is added to the sand, mix the sand well by hand.

4. Testing.—Test sand for permeability and strength only at this one moisture content. Record permeability and strength readings on three separate new sand specification cards (Fig. 8). Record also the name of sand, shipper and car number. One card is to be kept in plant file and the two other cards are sent respectively to purchasing and operating departments.

5. Complete Test.—A complete test may prove desirable whenever sand does not come up to the specification. In this case the sand tester will make a percentage clay and base permeability determination and mail sand grains to the Detroit laboratory. The procedure is identical to the monthly fineness test made on heap sand.

Conclusion

The use of the water measuring tube to bring the temper of every sand tested to a standard temper insures that every car of sand will be tested at the same moisture. The permeability and strength test will give sufficient information as to whether the sand comes up to specification. Should the bond be low, the strength test will read low. In case the strength test shows the bond to be correct and permeability test reads low, we may conclude the sand is fine as would be shown by a fineness test.

This report is supplemented by a detail list of test procedure to aid the sand tester in conducting the test. The sand tester should be furnished with this supplement.

Test Procedure

1. Obtain car number and name of sand and representative sample from the car of molding sand by use of the sand sampling tube Fig. 7.
2. Take samples four feet apart.
3. Quarter the collected sample pile and take handfuls of sand from each quarter to total a quart of sand. (Note: At plants where the sand tester works at night the sampling is to be detailed to some party as may be chosen by management.)
4. Dry the sample of sand in water bath heater or electric oven on top shelf—not over 212 degrees Fahr.
5. Let sample cool and crush lumps.
6. Weigh out 500 grams of sand.
7. Add the number of c. c. of water as stated on specification card for that particular card; for example, No. 4 Mills 50 c. c. or No. 2 Hatch 45 c. c.
8. Mix well by hand.
9. Test for permeability and strength at this moisture only.
10. Record all data on three separate sand cards (Fig. 8).
11. Cards for plant file, purchasing department and operating department.

DISCUSSION

CHAIRMAN BULL: Gentlemen, this is a rather comprehensive and highly instructive paper which gives considerable difficulty to one attempting to abstract it in a very short time. Those who have read the paper, and I hope a goodly number have read it, will appreciate the fact that Mr. Dietert has not, in his remarks, touched upon the plant comparisons which are the result of the permanent records made, and of the values that are established in routine practice. He indicates in the text that this has been a very helpful factor, which I can readily appreciate. I will be glad to have free discussion of the points made in the paper.

R. F. HARRINGTON: I will be glad to start the discussion by first of all expressing my feeling regarding this very fine paper that Mr. Dietert

has presented. To my mind, it is one of the finest papers ever presented at any of the conventions. Mr. Dietert has favored us with many other papers on molding sand work, but this particular one appeals to me especially. It so happens that we are doing similar control work in our plant, although it is on an entirely different character of sand, and I am happy to say that the very same satisfactory results that Mr. Dietert is obtaining through these methods of sand control we are obtaining.

J. T. MacKenzie: I would like to ask Mr. Dietert if he has any trouble with iron in the sand destroying the accuracy of his moisture tests?

H. W. Dietert: We are particularly blessed with a molding sand condition that does not place very much iron in the molding sand; some, but not very much. Certain foundries, of course, have work where there is a lot of iron in the molding sand because of the nature of the work. Vent holes produce iron in the sand, and the moisture test is affected by such iron. Probably you would have to riddle your sand; we used to riddle our sand just before we tested it, with a quarter inch riddle. Again you approach difficulties if your sand is hot and you riddle it, you lose a lot of moisture. Every floor should be treated individually. With this moisture indicator, by the way, you would have to have a lot of scales on the side if you want to make your readings show the per cent of moisture. In one particular foundry of ours we use eleven different kinds of sand, and we work on an arbitrary scale there. Say a certain floor works best compressed between 5 and 6; another floor with a different class of work may have to be compressed to 9, but we use the previous night's figures and in three or four months we have got it all standardized if it is the same crew.

Chairman Bull: Are the molding foremen and assistant foremen thoroughly sold with the idea that it is helpful to them?

H. W. Dietert: Our greatest trouble right now is to keep up with our foundrymen; they want to go too fast; we cannot produce practical things fast enough for them; probably that is the best way in which I can express it. I invite all of you to consult our foundry superintendents or assistant foremen or any of our sand wetters, the night crew themselves. In only one instance did we have any difficulty and that was in one of our plants when we first started; that was with the night crew; they thought it was going to create difficulty, that we were checking on them. We were not checking on them, we told them we were helping them. The work is carried out in all the plants with the idea of helping them, but the task was so much easier because we did pick out a good foundry to start with and the results there sold it to the other plants.

Chairman Bull: How long has the system been maintained?

H. W. Dietert: This system as it stands has been in about two years. Some of the plants have had it a little longer. We first worked on it six months in absolute control of one foundry, about a 90 ton foun-

dry. We had it in operation there before we extended the same system to the other plants. For about two years we have maintained this sand control, and the sand control is what our fellows go by. A fortunate thing was that wherever difficulties were encountered we were able to explain and correct them.

R. F. HARRINGTON: It occurs to me that in answer to the chairman's question as to whether the selling of the proposition to the foundrymen was done with great difficulty or not, that possibly I can throw a little light upon that. On a certain class of castings we had, certain difficulties arose, a certain character of defect. It was the judgment of the foundry department that, based upon their past experience, the thing to do with that particular heap of sand was to open it up with some fire sand for the purpose of carrying away the gases; in other words, it was the judgment of the foundry that the sand was not sufficiently permeable to take away the gases. Now it so happens that we have been operating that particular section of the shop for some three or four months with sand control. We had some very definite ideas as to what the permeability should be. This was in the early stages of our development work, and we went on record at that time as believing that the difficulty was not due to lack of permeability. Now that was based upon an experience of three or four months, our thought being that the permeability was the same on this particular day as it had been on the average for the past three or four months. All other elements remaining the same, there must be some other cause that was responsible for this defect in this particular group of castings. Desiring, however, to go to the limit with the practical foundrymen, we continued to add fire sand to that particular molding sand heap until the permeability figure went from 200 to above 300. This was a section of the shop involving only a few castings, so we could afford to do this for the purpose of demonstrating the value of sand testing. This heap was raised from 200 to over 300 permeability, and the defective castings still continued.

A barrel of graphite lead was changed at the suggestion of one of the men, and immediately the trouble disappeared, but the permeability had been raised from 200 to 300 with absolutely no effect. Now my point is this: that by that particular instance we sold our foundrymen the value of these permeability tests. I believe our foundrymen are well won over to the foundry control test method.

I have another question and that is the question of sea coal. In many shops, sea coal is not used to be sure, but in other shops, large quantities of sea coal are used and to date I have learned of no test whereby an exact knowledge of the sea coal content can be obtained in order to learn whether or not there has been an accumulation of the sea coal. Of course by these A. F. A. test methods we would notice a drop or an increase in permeability with these varying conditions of sea soal, because sea coal

is a very important factor in permeability determination. The idea is that as your sea coal accumulates (it is a fine material), the permeability of your sand drops down. The difficult problem is to determine whether the sea coal is accumulating or whether it is something else that is causing this drop in permeability. I wanted to ask Mr. Dietert whether he had considered the question or had occasion to run tests to determine the effect of the accumulation of sea coal which often causes defective castings?

H. W. DIETERT: We tried various tests in running sea coal content, but so far have been unsuccessful. Yet the tests would apply to a large number of floors or you could even devise a single test which would give accurately the sea coal content.

S. R. ROBINSON: I would like to ask Mr. Deitert what the difference was between his scrap before and after he used these sand control tests.

H. W. DIETERT: I do not want you to place too much confidence in our results secured by sand control, because it all depends on how thoroughly you apply it, and second, I am not dead sure whether our reduction in loss is solely caused by sand control. But sand control is the start of it. You can go back to the old loss sheets, and our loss used to run just like I know every other foundry runs, between 8 and 9 per cent on the same class of work. We are now down around 4 per cent in all plants, month in and month out.

One plant today is operating at 6.4 per cent loss, but that is not caused by sand. Herein comes the value of molding sand testing. We have had the 6.4 loss, but we have got the 4. average, but the 6.4 is not sand. This is where the value of testing comes in; when we have trouble or difficulty our men have confidence in the molding sand and are able to buck the proposition.

J. F. HARPER: In reply to Mr. Harrington; I believe it would be possible to determine the sea coal present in your molding sand by a b.t.u. test.

H. W. DIETERT: What about the accumulation of the sea coal, that is, ash, etc.? Would you include that as sea coal content or the effects of old sea coal, that is the combination of new and old? That is the test we are really interested in.

CHAIRMAN BULL: I think probably Mr. Harrington meant to include the new sea coal and residue from any sea coal, because they would both affect the permeability.

MR. HARRINGTON: Yes, sir, and I think though there is a lot of food for thought in Mr. Dietert's remarks.

J. T. MACKENZIE: Would not a much simpler test be combustion? It seems to me the combination of the fineness test and the permeability and strength test with combustion would locate the trouble.

R. F. HARRINGTON: I might reply to that by saying that considerable work has been done with the carbon combustion furnace for the purpose of determining the sea coal accumulation, but the results have been very unsatisfactory. There is something in the way of organic matter, something that throws the results entirely out of line and they are so entirely inconsistent that we do not know where we stand with the ordinary combustion method.

A. E. HAGEBOECK: I would like to ask Mr. Dietert a question: In his introductory remarks he referred to putting the water in the heap by means of a pipe. Will you tell us whether you threw the water on top of the heap or attempted to get it down into the heap?

H. W. DIETERT: In answer to Mr. Hageboeck's question we have holes in the end of the pipe which are about four feet long. The valve is to control the water. The end of this pipe is flattened out, and the worker sticks this pipe into the sand rick, going from the top to the bottom, absolutely down to the concrete floor. He punches a hole in the sand about every eight inches. For the second wetting down, you get it definitely by the meter.

MR. THOMAS: I would like to ask Mr. Dietert if he tests the sand as purchased and also whether in installing such a system he would put it in in its entirety or put it in partially and build up to it?

H. W. DIETERT: We make a strength and permeability test on every car lot of molding sand received, not so much with the idea of throwing the sand back to the producer, but of getting closer to him. We tell him what we want, we tell him what he has given us. We say, "That car was too weak last time, it only went 5 pounds; we want 6 pound sand." We have rejected a few cars but those cars that were rejected would have been rejected even if we did not have sand control. The receiving clerk goes out with his sand sampling tube, as illustrated in the pre-print, and goes down to the bottom of the flat car and withdraws it and has a sample from that section. Then he secures a sample from every four foot section and the samples so secured are placed in one pile and taken to the laboratory and marked as samples of a certain car. The sample is dried out and if it tested 8 per cent moisture, he adds 8 per cent moisture and tests it for strength. One record card goes to the purchasing department, one to the manager and the other stays in the superintendent's department and is marked accepted by the superintendent and the yard crew unloads it, but not before.

In regard to starting sand control in a foundry, I would say that if your man starting it has had no experience in sand control work, the best thing is to start with the most simple one, that is the A. F. A. permeability test, then take a strength test, then the moisture test, but work out one at a time. It is a good thing to have all three of them, but the

best way is the conservative way. If you give a man too much, he will learn it halfway and a little knowledge is dangerous.

A. A. GRUBB: One word in regard to Mr. Thomas's question: He has touched on a point that is of very live interest at present; that is the checking up on new sand. Just a little while ago, a producer called my attention to a fact which will bear on this question. This producer was shipping sand out of a certain pit and that sand was being tested by a test which measures its condition, not its content, and was being accepted by the foundry on such test. Then the recent drought ceased and wet weather set in. This test which measured a condition rather than the content of the sand, disclosed entirely different figures and he immediately commenced to turn down cars of sand. It means merely this: that we must apply these tests with extreme care in the acceptance and rejection of sands. I might say better in the sale and in the purchase of sand.

I am confident that you can take a sand at the pit and put a certain sand moisture content in it and it will give you one permeability and one bond, and that same sand with that same moisture content but treated differently or even soaked up by a good rain en route, will give you entirely different permeability and bond value. It means this, that we would be safe if we would check on content, say, the grain size and clay content and probably the quality of that clay, in talking purchases and sales. Personally I believe we had better be very careful with the permeability and bond tests in such cases, reserving them perhaps for use in controlling foundry heaps.

I wish to mention also that Mr. Dietert in his most valuable paper has certainly shown how these tests must be adapted to particular conditions in the foundry. I doubt if any one system of testing can be lifted from one foundry and placed in another with exactly the same satisfaction and result. I think all who have tried the various tests have found that they must adapt them to the particular condition in their foundry.

CHAIRMAN BULL: I think Mr. Grubb has touched upon a very important point when he said that; another important point was covered by Mr. Thomas' question and also by Mr. Dietert's answer covering the application to new shipments, that it needs to be approached with a great deal of caution. The author's text says in so many words, that rejection of car lot shipments is not practiced, for a greater mutual gain may be obtained by co-operation. I presume from that he means that his company has found desirable a degree of co-operation with the producers and yourselves?

The Life of Molding Sands

By C. M. Nevin, Cornell University, Ithaca, N. Y.

Among foundrymen the question of the durability of molding sands has often been discussed, but the results are inconclusive, as it is very difficult to make a comparative estimate of this factor of longevity. Yet it is common practice to speak of long-lived and short-lived sands, meaning that certain types do not burn out as fast nor need as much replenishment with new sand, as do other less durable sands.

Oftentimes certain Albany molding sands are cited as an illustration of long-lived ones, in contrast to some Lumberton, New Jersey, sands which seem to burn out rather quickly. However, when the writer tried to secure a representative series of short, medium and long-lived sands, that could be used as standards for comparison, the imperfectness of the present ideas on durability became at once apparent.

In fact many foundrymen would not venture to select typical short and long-lived sands, simply because their judgment was based on hearsay or on very hazy comparative data. Moreover, contradictory evidence was often obtained, since one particular sand might be considered as short-lived in a foundry doing a certain type of work, when another foundry using the identical material but under different foundry conditions, would suggest this sand as an example of a medium or a long-lived type.

So, although foundrymen in general appreciate the fact that there are short, medium and long-lived sands, and in a general way try not to use the less durable types, they are not always in a position to really be sure of their selection, let alone be able to size up a new and untried sand as to its durability. In addition with the present tendency to substitute nearby sources of supply in order to save heavy freight charges and with the growing application of testing methods to sand shipments and foundry control, the question of the comparative life of molding sands is daily becoming more important.

It would seem therefore that anyone attacking this problem of longevity should first consider the factors that influence the durability of a molding sand and then, after as many of these factors are made as constant as possible, to in some way measure the variables and thus form a series from long to short-lived. The closer the methods of testing approach the actual foundry conditions, the more valuable the results and the more weight may be attached to a comparison of one sand with another. If, in addition, a short-cut laboratory method can be devised which will test the most important factors influencing the durability, a long-felt need will be met.

In this connection, acknowledgements are due the members of the sand testing committee of the American Foundrymen's Association, collectively and individually, for their many practical suggestions; to Professor Wells of Cornell University, for the use of the foundry and a constant spirit of co-operation, the writer is greatly indebted; and to Dr. H. Ries under whom this research was conducted, the writer is under special obligation.

Factors Influencing the Life of a Sand

It is not intended to review here all of the possible factors that might affect the durability of a molding sand and as only the more important ones are discussed, doubtless the reader may think of some additional points.

1. *Quality of the Bond.* Under this heading should be included all of those vague, indefinable physical and chemical qualities that are reflected by unexplainable difference in the behavior of different types of molding sand. If all of the bonding material were of the same quality, kind or make up, the solving of this problem of longevity would be relatively simple. Perhaps no other one variable is harder to measure than this factor of quality and yet it is one of the most important and least understood. No single test will adequately evaluate its influence, and an approximation is the best that can be hoped for at present.

2. *Amount of the Bond.* If all of the sand in a mold were subjected to the same heat influence, the amount of bonding material would not be so important and a simple test to give comparative durabilities might be easily devised. However, since the

molding sand is progressively burnt out, from the casting as a center, the effect of the total amount of bonding material is very influential when making comparisons of longevity. It is evident that of two sands having the same quality or kind of bond, the sand with the greatest amount of that bond would have the longest life.

So this variable of "amount" must be measured or estimated in order to get a true comparison between either similar or totally different sands. Unfortunately our present methods of testing, whether applied to molding sands or to the study of soils, do not separate the factor of amount from that of quality, but test them as a unit and call it strength, cohesiveness or colloidal condition of the sand.

3. *Rehydratability.* With the tempering of a molding sand the bonding material takes up water, swells, becomes sticky and gives strength to the sand. It has been demonstrated[1] that the amount of water a molding sand will require in practical use, is quite variable depending on the amount and quality of the bonding material present. For instance, J. Van Bemmelen found[2] that ferric oxide when just dry at 15 degrees Cent. would take up over six molecules of water per molecule of ferric oxide, which is one reason why some molding sands take up much water without feeling very wet.

This ability to take up water is destroyed to a varying degree upon exposure to the heat of casting. Iron oxide, for example, dehydrates very easily, but readily hydrates again, which is unlike clay which may "porcellanize" through heating and not retemper. So this property of rehydratability is a variable, directly affecting the life of the sand and it is of such importance that a further discussion is later given in this paper.

4. *Oxidizing and Reducing Conditions.* When the sand in a mold is examined after the casting has cooled, a zonal arrangement of colors is noticeable due largely to the changes in the oxidation of the iron in the bond. Immediately next to the casting, the molding sand has been burnt to varying shades of black, grey and

[1]C. M. Nevin, The Relation of Water to Bonding Strength and Permeability Trans. Amer. Fdry. Assoc., Vol. 32, Part 2, 1925, pp. 168-181.

[2]J. M. Van Bemmelen, Die Adsorption. 1910. Dresden.

sometimes almost white showing that the conditions here must have been of a reducing nature. A little farther away from the casting the sand is usually changed to some shade of red or reddish brown, showing that oxidizing conditions existed in this zone. In turn this reddish color grades into the unchanged color of the molding sand, due to the quickly diminishing effect of the heat. The width of these zones depends largely on the size of the casting and the permeability of the sand.

So it would appear that both oxidizing and reducing conditions are obtained in foundry practice. This statement assumes more importance when we remember that clay behaves similarly, for if fired under reducing conditions it fuses at a much lower temperature than when heated in an oxidizing atmosphere. Thus any testing method which is designed to give a durability or life factor by heating the sand under either entirely oxidizing or entirely reducing conditions, is open to the criticism that it is not comparable to actual foundry practice.

5. *Fusion Point.* There is no necessary direct connection between the fusion and durability of a sand. A molding sand may have a low fusion point but a large amount of bonding material and a high rehydratability and thus a long life. However a sand that fuses easily often has a large proportion of its burnt material pulled out with the casting and thus the heap is not contaminated and stands up well. Such a heap is oftentimes in better condition than that of a sand with a longer life, which may have a tendency to not fuse so easily and so leave some of the partially burnt sand behind in the heap, instead of being removed with the casting. Of course over a considerable period of time it would be an easy matter to discover which sand required the largest addition of new material.

6. *Size of Casting.* Manifestly the size of the casting controls to a large extent the effective zone of heat influence as well as the length of time the sand is subjected to such heating. The larger the casting the farther out the heat effect will extend and the longer it will take to cool off.

7. *Pouring Temperature.* Steel, iron and brass all have different heats of pouring, which naturally is reflected by the speed

with which the sand deteriorates. In fact the pouring temperature of any of these metals may vary over a considerable range and metal poured hot is much more destructive to the sand than metal poured sluggish.

8. Permeability to Gases. Other things being equal the sand with the best permeability will have the longer life because the hot gases are conducted away quickly. This is one reason why a fine grade of sand with a really long-life, is often unjustly con-

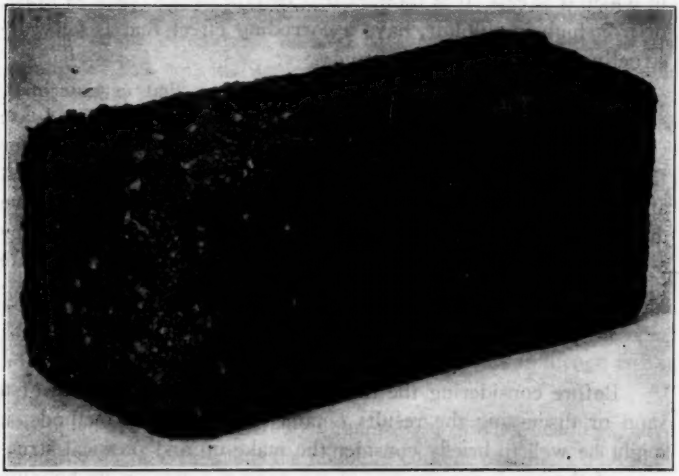

FIG. 1—CASTING SHOWING GREATER FUSION OF SAND ON BOTTOM OF CASTING WHICH IS TO THE LEFT IN ILLUSTRATION

demned as short-lived when used for large castings, because the permeability is low and the heat is not conducted away as quickly as it should be.

The picture of a casting made in Millville fine gravel, Fig. 1, shows clearly how effective is heat conduction and permeability, in protecting the bond. It is very noticeable that near the top, where the heat can easily escape, no appreciable fusion has occurred, which is in contrast to the bottom, where the sand has stuck tightly.

9. Tempering Water. In addition to the effect of too little or too much water on the venting and strength properties of a

sand, the amount of water has a further influence on the life. A sand tempered wet, with much more water than is necessary, will resist the heat effect of casting much better than when tempered with the usual amount of water. This excess water acts as a protective film and the deterioration of the sand is not so rapid.

10. Character of Metal. The effect of the composition of the metal, in addition to the differences in the pouring heats of different metals, exerts some influence on the durability of the sand in which it is cast. It is thought that certain metals, such as brass, or iron high in sulphur, have a corroding effect that is very destructive to the bond of the sand.

Summing up these factors it is evident that certain ones, such as the quality, amount and rehydration of the bond are variables that very largely control the life. Many of the other factors can be made more or less constant when devising a test and if thus taken care of, will not greatly affect the comparative durabilities of a series of sands. It would seem therefore that by a proper balancing and control of these factors, a fairly accurate idea of relative longevity is not hopeless.

Structure of the Bond

Before considering the methods of determining the life of a sand or discussing the results obtained by any such methods, it might be well to briefly consider the make-up and physical structure of the bond, for the life of the sand depends on its bonding material.

For a long time it has been recognized that the bond is composed of matter in a colloidal state, which will easily swell and become sticky upon the addition of water. That is, these colloids should not be considered as chemical individuals, but should be thought of as matter in an extremely fine state of division.

Robinson and Holmes[3] state that colloidal silica, silicates and humus and colloidal hydroxides of iron, alumina and manganese exist in the soil. Of these colloids, silica and hydrated iron and alumina are doubtless the most important in molding sand. Upon subjection to heat this colloidal state is destroyed to a greater or lesser degree and the ability to rehydrate and become sticky again

[3]The Chemical Composition of Soil Colloids. U. S. Dept. Agr. Bull., 1311, 1924.

is also proportionately lost. A sand that is completely burned out has had the colloidal condition destroyed by the high heat and will not rehydrate.

J. M. Van Bemmelen[4] has noted that colloidal oxides of alumina, iron and silica, unless dehydrated too far will eagerly take up water again, but they do not take up as much as they had previously, nor does the volume return to its original size.

Consequently it would appear that the burning out of a sand is really a destruction of the colloidal condition of its bond and if we had some dependable method of measuring the amount and quality of this colloidal material, the problem of relative durability would be nearly solved.

Present Methods of Measuring Colloidal Material

Methods of determining the amounts of colloids in soils or molding sands have not been sufficiently developed to obtain any great degree of accuracy and at best the measurement is only an approximation. Such methods as the bar test, compression test and tensile test, which are now being used to judge molding sands, show the variables of quality, amount and rehydration of the bond at one and the same time without showing what influence is exerted by each of these factors.

Eighteen possible methods, under eight distinct headings, have been listed for measuring the colloidal content of soils. The very fact that there are so many methods, would seem to indicate that no satisfactory test exists for measuring colloidal material. Of all these methods[5] the dye adsorption test is considered to hold the best promise of a successful answer, but the writer does not concur in this opinion because of the following reasons:

1. The concentration of the final unadsorbed dye must be controlled within narrow limits or mass action gives abnormally high results.

2. The arriving at an easily duplicated condition of equilibrium within a reasonable length of time, requires very careful manipulation of the test.

[4]Zeitschr. Anorg. Chem., 62, 1909.
[5]Estimation of colloidal material in soils by adsorption. U. S. Dept. Agr. Bull., 1193, 1924.

3. Any type of dye varies somewhat in its quality, depending on the source of supply, so that comparative results between different investigators is difficult to obtain.

4. No dye is a specific for all types of colloids and the only certain fact is, that a basic dye is more readily adsorbed by an acid colloid and vice versa. Accurate work would therefore require the testing of a molding sand with both basic and acid dyes.

5. Dye adsorption is mostly a surface measurement and does not definitely define the quality or rehydratability of the bond.

Table 1

DYE ADSORPTION QUALITY OF SANDS

Heat Treatment	Green	150°	250°	350°	450°	550°	650°	750°	850°	1000°
South Albany	360	340	314	272	112	112	120	116	112	24
Kentucky stove	650	600	520	440	308	276	272	272	176	36
Coarse Albany	476	460	440	312	304	240	236	230	208	24
North River	500	480	408	312	272	240	204	204	176	32
Lumberton	1005	980	952	712	540	476	368	368	240	24
Coarse Jersey	612	564	520	376	340	276	240	240	240	24
Ohio—4 R. B.	1100	1000	952	744	508	476	352	336	340	20
Ohio—Wilbren	1040	1000	880	680	604	348	272	260	208	24

The temperature is degrees centigrade taken with a platinum couple. One hundred grams of molding sand were heated for twenty minutes in a gas muffle at the above temperatures. Twenty-five grams were used for the dye test. Figures are milligrams of crystal violet dye absorbed by 100 grams of molding sand.

Fine silica flour will give a dye adsorption test figure, but of course has little strength or rehydratability.

Therefore it would appear that dye adsorption might give some interesting figures on the amount of the colloids present but nothing dependable on the quality of the bond. For these reasons, in comparing any series of markedly different molding sands, the dye test gives disappointing results.

Over a year ago Walter M. Saunders kindly furnished the writer with a series of dye adsorption tests on eight different sands which had been subjected to heat treatments. These figures of Table 1 are extremely interesting and with his permission are published here for the first time. They show very clearly the destruction of the colloidal condition with each increase in temperature and Mr. Saunders is to be congratulated on this piece of pioneer work.

The sharp break above 850 degrees indicates that no matter what type of bond is present, it is not able to withstand such a temperature and is completely burnt out. That this series shows the comparative life of these sands is doubtful, for the reasons already given.

Foundry Test

At the very outset of this investigation on durability it became evident that, if a group of sands were heat treated alike and then tested by the bar or by a compression method, an interesting series would be formed. So the following method was worked out and every effort made to keep conditions as nearly as possible in accord with foundry practice.

Table 2

No.	Locality	Grade	Maximum Strength	Maximum Permeability	Remarks
1	Mt. Olive, Tenn.	1½	390	55	Large amount of ferric oxide
2	Lumberton, N. J.	2	298	75	A few green-sand particles
3	Albany	1½	174	20	Typical
4	Bowling Green, Va.	0	154	56	Mealy feel when tempered
5	Richmond, Va.	2	276	17	Green-sand grains
6	Stafford C. H., Va.	1	230	20	Green-sand grains
7	Lumberton, N. J.	2	308	62	Typical
8	S. Amboy loam	0	257	9	Very clayey and hard to temper
9	Lumberton, N. J.	2	278	107	Typical
10	Madison Hts., Va	1	264	16	Lumpy when tempered
11	Milville	6	260	900	Easily over-tempered
12	Port Republic, Va.	1½	200	16	Full of organic matter
13	Albany strong	0	196	10	Typical
14	Albany weak	1½	121	44	"
15	Albany strong	1½	174	18	"
16	Albany	3	161	60	"
17	Dansville, Pa.	0	160	10	"
18	Newport, Ky.	0	202	8	"
19	Albany weak	2	145	47	"
20	Nickel Plate, O.	0	167	20	Mealy feel when tempered

Twenty well-known molding sands were chosen including weakly and strongly-bonded types, coarse and fine grades, open and poorly venting varieties and sands of widely differing physical and chemical characteristics. With such a series it was hoped that large enough differences would be developed upon heat treatment, so that any slight mechanical inaccuracies in the testing methods, would not have much influence upon the final deductions.

Table 2 shows some of the properties of these twenty sands before heat treatment. They are all used daily in the foundry and include some of the best known types in the United States. The grade was determined by the area curve method[6], the strength by the A. F. A. standard bar method and the permeability by the A. F. A. standard orifice method.

Four thousand grams of each sample were tempered with the right amount of water necessary to develop the best strength and

[6] C. M. Nevin, Notes on the Grading of Molding Sands. Trans. Amer. Fdry. Assoc., 1926. Vol. 32, Part 2, pp. 182-219.

rammed up in a straight-sided, tin flask 5 inches by 5 inches by 7 inches, around a wooden pattern. The pattern was then pulled and a grey iron casting poured, which was allowed to become cold before removal.

A total of four castings were made in each sand, with a circular cross-section of 1¼ inches and a length of about 5 inches, before it was decided that the heat effect from such a small casting was not strong enough. Beginning with the fifth heat, the casting in each sand was increased to a square cross-section of 2¼ inches and a length of about 3 inches. Considering the bulk of the sand samples and the rate of burning out, this size of casting was found to be about right.

One type of grey iron was used in all of the castings and the pourings were made at the same stage in the heat so that the temperatures were as uniform as practicable.

After cooling, the castings were cleaned with a coarse rasp, the burned sand thus obtained being thoroughly mixed with the sand in the tin flask. The sample was then tempered with the right amount of water to develop the maximum strength and tested by the A. F. A. bar test, the compression method and for permeability. The bar and permeability tests were made according to the standard methods, the sand being allowed to temper twenty-four hours before testing.

The compression test was made on a 2 inch by 2 inch sand core, which was rammed up as for the permeability test, and broken in a lever type of machine, similar to a Riehle machine. It is appreciated that the compression strength figures given by such a test piece are too large because of the height of the specimen. However, if the height were increased to a theoretical ratio, non-uniformity of compaction would enter and probably make the results too low. Since the compression results are used only for a comparison of sands within this group of twenty, it is thought that no inconsistency is developed by using such a test specimen. The average of three tests, checking within eight percent of each other, was taken as the compression figure.

No new sand was added during this heat treatment and care was used to save all of the heat-treated sand, so that at the tenth heat, plenty of sand was still available for the tests.

With a testing method such as outlined, the factors that influence the life of a sand have either been made constant or are reflected in the tests. The quality, amount and rehydratability of the bond are expressed by the strength tests with a single figure. Oxidizing and reducing conditions are similar to those in actual practice. The size of the casting is constant and the pouring temperature is as uniform as practicable. Permeability to gases is given as well as the grade of the sand, which is determined by the area curve method.[7] The sand is tempered each time to its maximum strength and the kind of metal cast is a constant factor.

So it would seem that we have here a durability test method that closely approaches actual practice in the foundry; one which will give results that are understandable and dependable.

Sands Require Different Amounts of Water for Tempering

Before going into a critical analysis of the results, it might be well to point out that many sands on being subjected to heat treatments, require different amounts of tempering water for the maximum strength, than they do in their green condition. This is to be expected, especially for those sands high in colloidal content, as the destruction of some of the colloids would force the remaining colloids to become overtempered, if the same amount of tempering water were used as was required before burning. In this overtempered condition the sand would appear weaker and further burnt out than it really is, and erroneous conclusions would be drawn. The data in Table 3 illustrates this point, and shows that while the amount of optimum water is only slightly affected in some sands, a decrease of four or five percent is not unusual.

Extreme care must be used in determining what amount of water is required after each casting heat to give a maximum strength. At least two and often three trials at different water contents are necessary to determine the optimum or "best" amount. Too much emphasis cannot be placed on the necessity for careful tempering, as otherwise very misleading strength results will be obtained.

[7] C. M. Nevin, Notes on the Granding of Molding Sands. Trans. Amer. Found'ns. Assoc., 1925. Vol. 32, Part 2, pp. 182-219.

Permeability Changes as Sands Are Used for Casting

It might also be of interest to point out that with continued heat treatment a molding sand often changes in its permeability

Table 3
RELATION OF THE OPTIMUM WATER TO HEAT TREATMENT

No.	Locality	Percentage of Water for Maximum Green-Strength	Optimum Water Required at the Last Heat Treatment
1	Mt. Olive, Tenn.	13.1	9.8
2	Lumberton, N. J.	4.5	4.1
3	Albany	5.4	4.3
4	Bowling Green, Va.	4.3	3.7
5	Richmond, Va.	7.0	6.0
6	Stafford, Va.	7.0	5.5
7	Lumberton, N. J.	8.6	5.7
8	South Amboy, N. J.	14.1	9.1
9	Lumberton, N. J.	5.0	3.9
10	Madison Hts., Va.	9.3	9.1
11	Milville, N. J.	6.0	6.0
12	Port Republic, Va.	8.0	6.3
13	Albany, strong	5.0	5.0
14	Albany, weak	5.8	4.1
15	Albany, strong	5.0	5.0
16	Albany	6.6	6.2
17	Dansville, Pa.	5.0	4.6
18	Newport, Ky.	7.3	5.8
19	Albany, weak	4.0	4.0
20	Nickel Plate, O.	5.2	4.7

to gases. The following data in Table 4 summarizes this condition by comparing the maximum permeability after heat treatment.

As a general rule the permeability increases, which is especially noteworthy when it is remembered that the burnt sand was scraped off the casting and returned to the sample. Such sands as Nos. 1 and 16, owe their large increase in permeability to the formation of compound grains, which show up nicely under the microscope. So perhaps this usual increase of most of the sands in permeability with heat treatment, may be attributed to a compound grain formation. The slightly lowered permeability for No. 11, a fine Milville gravel, is perhaps due to the forming of some fines from the burnt material.

In this connection the writer wonders if the complaint of decreased permeability in the foundry heaps because of continued use is not often really due to the increase in fine sea-coal, rather than to the deterioration of the molding sand.

Effects of Heat Treatment

Coming now more directly to the relative life or durability of molding sands, Table 5 gives in a summarized form, part of a

large mass of data that was secured by using the bar test, to show the effect of heat treatment on this series of twenty sands. These tests were carried out according to the standard methods, and each

Table 4

RELATION OF PERMEABILITY TO HEAT TREATMENT

No.	Locality	Maximum Permeability When Green	Maximum Permeability After Last Heating
1	Mt. Olive, Tenn.	55	156
2	Lumberton, N. J.	75	96
3	Albany	20	26
4	Bowling Green, Va.	56	55
5	Richmond, Va.	17	31
6	Stafford, Va.	20	34
7	Lumberton, N. J.	62	94
8	South Amboy, N. J.	9	8
9	Lumberton, N. J.	107	90
10	Madison Hts., Va.	16	16
11	Milville, N. J.	900	780
12	Port Republic, Va.	16	22
13	Albany, strong	10	21
14	Albany, weak	44	56
15	Albany, strong	18	34
16	Albany	60	146
17	Dansville, Pa.	10	18
18	Newport, Ky.	8	10
19	Albany, weak	47	52
20	Nickel Plate, O.	20	36

Table 5

RELATION OF STRENGTH TO HEAT TREATMENT AS SHOWN BY THE BAR TEST

Sample	Grade	Green	Heat 2	Heat 5	Heat 6	Heat 7	Heat 8	Heat 9	Heat 10
1	1½	290	+	142	130	85	+	74	54
2	2	198	194	52	46	36	5	out	out
3	1½	74	71	31	26	23	7	5	out
4	0	54	45	18	out	out	out	out	out
5	2	176	176	98	95	52	+	37	34
6	1	130	130	92	75	60	+	33	28
7	2	208	185	78	71	54	9	out	out
8	0	157	156	94	93	+	87	+	69
9	2	178	140	42	33	9	out	out	out
10	1	164	164	125	118	+	101	+	77
11	6	160	160	67	59	45	26	9	out
12	1½	100	100	77	68	45	43	39	37
13	0	96	90	50	35	30	20	6	out
14	1½	21	21	3	out	out	out	out	out
15	1½	74	65	32	27	21	14	11	13
16	3	61	61	42	24	7	out	out	out
17	0	60	55	41	34	20	16	14	15
18	0	102	100	81	63	+	49	40	30
19	2	45	40	18	out	out	out	out	out
20	0	67	60	27	18	9	out	out	out

All figures are maximum "available" strength.
+ Heat treated but not tested.

figure represents the maximum strength of the sand as determined after varying the tempering water until the optimum was obtained. It would serve no useful purpose to give all of the data

secured, except perhaps to show the care with which the work was carried out.

In expressing these results it was decided not to show the total strength figure but to deduct 100 from the figure obtained and call the result the "available" strength. This was done because it was found that below a breaking strength of 100 grams the sand was very weak, concordant results were difficult to obtain, and oftentimes the surface tension and shape of the grains were being tested rather than the effect of the bond. So the sand was considered to be burnt out, to all intents and purposes, when it gave 100 grams or less by the bar test. The figures in Table 5 are each 100 grams less than the breaking strength and they thus represent the real strength available for use in the foundry.

As already explained, after using the small cylindrical casting in four heats, the effect on the strength was found to be very slight. The results of the tests on the third and fourth heat are not included in this table as they practically duplicated those given for the second heat. The sudden decrease in strength with the fifth heat is due to the increased heat effect of the larger casting, which was substituted in this heat and used in all of the succeeding heats.

Even a cursory examination of the results brings out the fact that some of the sands decrease in strength quite rapidly, while others deteriorate more slowly. Moreover it is noticeable that this decrease is often not regular. This is perhaps because some of the sands may be bonded with more than one type of colloidal material which would necessarily give a non-uniform deterioration.

If now the life or durability of molding sand depends entirely on the amount of the bonding material, it would seem reasonable to suppose that the sands with the largest green strength would have the longest life. To demonstrate the fallacy of this conception and to bring out the additional influence of the factors of quality and rehydratability, the twenty sands are arranged in the descending order of their available green strengths and compared with a series formed after heat treatments, arranged according to their durability.

By comparing the two series shown in Table 6, several very interesting deductions may be made. The influence of the factor "amount" of bonding material is evident from the fact that the three most weakly bonded sands, Nos. 4, 19 and 14, were the first three to burn out, even though two of them are Albany sands, which have a reputed long life. In contrast to these, the strongly bonded Albany sands Nos. 13, 3 and 15, have comparatively a much better durability as shown by their position in the life series, simply because they originally had a larger amount of bonding material and therefore a larger reserve strength.

Table 6

COMPARATIVE SERIES OF STRENGTHS
BEFORE AND AFTER HEATING TREATMENTS

Before Heating		After Heating	
Sample No.*	Green Strength	Sample No.*	Strength
1	290	10	77
7	208	8	69
2	198	1	54
9	178	12	37
5	176	5	34
10	164	18	30
11	160	6	28
8	157	17	14
6	130	15	13
18	102	11	out at 10th
12	100	13	out at 10th
13	96	3	out at 10th
3	74	7	out at 9th
15	74	2	out at 9th
20	67	9	out at 8th
16	61	20	out at 8th
17	60	16	out at 8th
4	54	19	out at 6th
19	45	4	out at 6th
14	21	14	out at 6th

* Arranged in order from strong to weak sands.

Moreover the three Lumberton sands, Nos. 7, 2 and 9, which occur in this sequence when tested green, keep the same relative order after burning, with No. 9 the most weakly bonded, burning out first. Summing up these illustrations it seems certain that the factor of "amount" of bond is very important in determining the durability and always must be evaluated.

That the additional factors of "quality" and "rehydratability" are also influential, is apparent from the fact that the Lumberton sands, which are at the top of the series when unheated, fall away down to near the bottom after heat treatment. In other words, they are short lived in spite of their large amount of bonding material and high green strength.

On the other hand, Nos. 10, 8 and 12, because of the quality and rehydratability of their bond, are long lived and move up to near the top of the life series.

Summarizing these sands by districts, it is evident that the six Albany sands just about hold their own and occupy the same relative position in the life series, that they do before heat treatment. The writer considers the best Albany sands to be medium lived, rather than long lived and their comparative durability depends on their original strength, which is about of a medium character. In other words, a weakly-bonded Albany sand would have a relatively short life and a strongly-bonded Albany sand would have a medium life.

The Lumberton sands of this series are short lived no matter what their strength in the green state. A strongly bonded Milville shows up as medium lived, while the stove-plate sands from Dansville and Newport have a much longer life than the same grade of Albany sand. Loams such as Nos. 8 and 10 are very durable and the Virginia sands, Nos. 5 and 6, also show up well. The Nickel Plate, Ohio sand No. 20 and the No. 4 Virginia brass sand are short lived.

Comparison of the Bar and Compression Methods in Determining Durability

Some discussion has arisen lately regarding the relative merits of the bar and the compression methods in determining the bonding strength of molding sands. To see if different conclusions might be developed when judging the effect of heat treatments, compression tests were made on two inch specimens each time a bar test was made, so that the tempering and deterioration of the sand would be the same when tested by either method.

Table 7 summarizes these results, the compression figure representing the maximum breaking strength in grams minus 2000. It was found that at 2000 grams or less, the sand was so weak that concordant results were difficult to obtain, and therefore the sand was considered to be burnt out when such a figure was reached. Thus, by deducting 2000 grams, an "available" compressive strength figure is obtained.

In a great many cases it was noticed that the maximum strength in compression was secured with a lower percentage of water than that required for the maximum strength of the bar test. In fact the sand would often really feel under-tempered when the maximum compressive strength was reached.

Table 7

RELATION OF STRENGTH TO HEAT TREATMENTS AS SHOWN BY A COMPRESSION METHOD

Sample	Heat 2	Heat 5	Heat 6	Heat 7	Heat 8	Heat 9	Heat 10
1	12200	9680	8000	6000	3850	2480	2245
2	11570	2392	1760	1090	out	out	out
3	5215	2866	2370	1920	1350	990	out
4	2308	380	out	out	out	out	out
5	11235	5535	4200	2980	1765	1645	1630
6	9590	5200	3463	2870	+	1525	1405
7	10275	4107	4078	2290	1248	out	out
8	11325	9000	7900	+	5695	+	4663
9	7700	1160	490	210	out	out	out
10	15000	12100	10210	+	8530	+	6000
11	9350	4295	3125	2090	1210	130	out
12	8000	6715	5870	4290	4160	3100	2770
13	5322	2690	2255	2160	1553	1060	out
14	1702	830	365	out	out	out	out
15	4200	2495	2300	1987	1180	725	900
16	6000	4155	2910	1500	624	out	out
17	4665	2420	2200	1570	1380	430	500
18	7945	5645	4510	+	2940	2890	1840
19	2206	950	340	out	out	out	out
20	3340	1200	740	out	out	out	out

All figures are available grams compressive strength.
+Burned but not tested.

Table 8

COMPARISON OF THE BAR AND COMPRESSION SERIES

Bar		Compression		Bar		Compression	
Sample* No.	Heat 2	Sample* No.	Heat 2	Sample* No.	Heat 10	Sample* No.	Heat 10
1	290	10	15000	10	77	10	6000
2	194	1	12200	8	69	8	4663
7	185	2	11570	1	54	12	2770
5	176	8	11325	12	37	1	2245
10	164	5	11235	5	34	18	1840
11	160	7	10275	18	30	5	1630
8	156	6	9590	6	28	6	1405
9	140	11	9350	17	14	15	900
6	130	12	8000	15	13	17	500
18	100	18	7945	11	out 10	13	out 10
12	100	9	7700	13	out 10	3	out 10
13	90	16	6000	3	out 10	11	out 10
3	71	13	5322	7	out 9	7	out 9
15	65	3	5215	2	out 9	16	out 9
16	61	17	4665	9	out 8	2	out 8
20	60	15	4200	20	out 8	9	out 8
17	55	20	3340	16	out 8	20	out 7
4	45	4	2308	19	out 6	14	out 7
19	40	19	2206	4	out 6	19	out 7
14	21	14	1702	14	out 6	4	out 6

*Arranged in order from strong to weak.
All test figures are "available" maximum strength expressed in grams.

In Table 8, a comparison of the results of the series arranged by the bar test and by the compression method, show some differences when the sands are only slightly burned, as for instance after the second heat. Yet upon reaching the tenth heat, the final arrangement of the sands as given by the compression method is quite similar to that given by the bar test. In this particular case it does not seem to matter much which of these two methods is used, since the main interest lies in the durability of the sand and not in its original green strength.

However it is thought that the bar test method more nearly measures the stresses to which the sand is subjected in the foundry, so the bar series will be used in this paper as a standard of durability.

Need of a Simple Laboratory Test

One drawback to the method of determining the durability as outlined, is the time required to completely burn out a sand. Of course it is not necessary to test the sand after each burn, since the fingers and thumb will serve as a fairly good guide, until the bond has been pretty well destroyed. Even by using this short-cut, the method is still rather slow, although it has the advantage of closely approaching foundry conditions.

Since we have now established a standard life series for comparison, it was thought advisable to try several shorter methods and check the obtained results against the standard series. If a shorter laboratory method could be found, that would arrange the twenty sands in the same order as given by the method of making successive castings, quite an advantage would be gained.

Heating at 600 Degrees Fahrenheit

The first short-cut method tried was one similar to that suggested by H. W. Dietert[8] and also recently used by M. S. Littlefield[9] on some Illinois sands. Briefly their method is to heat a sample of sand in a furnace to 600 degrees Fahr. for a period of

[8]H. W. Dietert, Commercial Application of Molding Sand Testing. Trans. A. F. A., 1925. Vol. 33, Part 2, pp. 24-52.

[9]M. S. Littlefield, An Investigation of the Molding Sand Resources of Illinois. Rpt. No. 3, Illinois Geological Survey. See also Trans. A. F. A., 1925, Vol. 33, Part 2, pp. 359-391.

two hours and express the resulting loss in strength by the percentage of the original green strength.

Several investigators who have tried this method have been unable to get checks on duplicate runs because of the non-uniformity of the heat in the oven and also because of the poor heat conductivity of the sand itself. For instance, the part of the sand sample next to the container seems to be burnt more than it is further away from the outside, as is shown by the color of the iron oxides in the bond.

In order to guard against non-uniformity of heating, a large oil-fired kiln was used, during this investigation, with a muffle of 14 inches x 20 inches x 30 inches. This kiln was heated very slowly, in fact three hours being taken to reach the temperature of 600 degrees. This temperature was then held for two hours

Table 9

ARRANGEMENT OF SAMPLES IN THE KILN

Burn 1	Burn 2
Top of kiln	Top of kiln
17	11
19	18
1	2
Thermometer	Thermometer
2	1
18	19
11	17
Bottom of kiln	Bottom of kiln

within a tolerance of plus or minus 15 degrees. The temperature was read from a special precision high temperature thermometer, which was imbedded in the sand sample.

An eleven hundred gram sample of sand was used in each test, the sand being spread out in a large porcelain container so that the depth was a little over one-quarter of an inch. Six of these samples were fired at one time, the containers being supported so that a free circulation of the heated air was possible around each one.

A duplicate run was made, the position of the samples being reversed in this check run, so as to determine the possible effect of any non-uniformity of heating. The positions of the samples in the two burns are given in Table 9.

Strength tests were made by the standard bar method and the check samples were tempered as nearly as possible like those

of the first run. In each case the samples were tempered with the optimum water so as to get the maximum strength for each particular sand.

It would seem from the data of Table 10 that the effect of non-uniformity of heating has been overcome by using such a large kiln, by applying the heat very slowly, and by having the sand spread in a thin layer. In fact the tests check within the limits of error of tempering and within the mechanical inaccuracies of the bar test. No change in the color of the bonding material was

Table 10

DUPLICATE RUNS AT 600° F.

Sample	Burn 1 Percent Water	Strength	Burn 2 Percent Water	Strength	Average Strength
1	13.0	315	13.0	294	305
2	4.5	215	5.2	199	208
11	7.0	185	7.0	203	195
17	4.9	160	5.4	150	155
18	6.5	217	6.3	208	212
19	5.0	117	5.4	121	119

Table 11

Sample	Green Strength	Strength at 600° F.	Loss of Strength	Percent Loss
1	390	305	85	21.8
2	298	208	90	30.2
4	154	155	0	0.0
7	308	200	108	35.1
11	260	195	65	25.0
12	200	205	0	0.0
13	196	156	40	20.4
16	161	140	21	13.0
17	160	155	5	3.2
18	202	212	0	0.0
19	145	119	26	17.9
20	167	137	30	18.0

noticed, between the outside layer near the container and the sand further away.

Twelve of the series of twenty sands were treated in this manner, tempered with the optimum water to develop maximum strength and tested by the bar method. The results are given in Table 11.

Two inherent weaknesses seem to undermine the assumption that such a method will give comparative durabilities—

1. The bonding material in many molding sands is often made up of more than one type of colloid and it is doubted if any

test made at only one temperature will give a fair comparison. It is thought that the bonding properties might not be destroyed at a uniform rate, some types going to pieces quickly at a certain temperature which might be critical for that particular colloid. It is suggested that a percentage comparison between determinations made at a low and at a high temperature might give truer results.

2. By expressing the durability as a percentage of the loss of green strength, the factor of "reserve strength" is not given proper weight. For instance, a sand with a very low reserve strength might lose only twenty per cent of its strength and yet be much weaker and more nearly ready for the waste heap than a sand with a large available or reserve strength, which might show a loss after heating of fifty per cent of its green strength. Good

Table 12

COMPARISON OF THE STANDARD WITH THE 600° F. SERIES

Standard Series		600° F. Series	
Sample*	Strength After Heat Treatment	Sample*	Percent Loss
1	54	18	0.0
12	37	12	0.0
18	30	4	0.0
17	15	17	3.2
11	out 10th	16	13.0
13	out 10th	19	17.9
7	out 9th	20	18.0
2	out 9th	13	20.4
20	out 8th	1	21.8
16	out 8th	11	25.00
19	out 6th	2	30.2
4	out 6th	7	35.1

*Arranged in order from strong to weak sands.

illustrations of this are the short-lived Virginia brass sand, No. 4, and the long-lived Tennessee red sand No. 1.

Comparing the relative life as determined by this method (Table 12) with that of the standard foundry test series, several inconsistencies are apparent. Some of the long-lived sands are found near the bottom of the series, while some of the very short-lived types move up to the top. In fact the results secured by this short-cut method are quite disappointing, if we are to accept the series determined by successive castings as a standard.

As far as the writer is aware, no previous check has been made on this short-cut method to see if it really gives a comparative durability of molding sands. No doubt it was the original intention to use this method only as an approximation, but since

it fails to check the standard series and because of its inherent weaknesses, much of the information obtained through its use will perhaps be very misleading.

The Relation of Dehydration and Rehydration of the Bond to its Durability

It has always seemed to the writer that colloidal conditions are the controlling factors in any investigation of the bonding material of molding sands. So in casting around for some suitable laboratory method of measuring the destruction of the bond, a colloidal measurement was sought. Unfortunately the present methods of colloidal measurement are not satisfactory and indeed are only an approximation. However, studies along this line of investigation have been made on soils, and some of the results are very interesting.

For instance, A. B. Beaumont[10] shows that igniting soils does not destroy their ability to take up moisture from a more or less saturated atmosphere, contrary to the frequent assertion that it does. In fact this rehydration after heating is often quite appreciable, in some cases amounting to ten per cent.

J. W. Mellor[11] says that the combined water in kaolinite, one of the few definite minerals of clay, is not all of the same nature. Two molecules are water of crystallization, and the other ten molecules are water of constitution. Regarding the dehydration of kaolinite, I. Samoylov[12] points out that practically all of the water is driven off between 450 degrees and 550 degrees Cent.

Applying these ideas to molding sands it would seem possible that there might be a difference in rehydratability of the bond of different sands and that even above 500 degrees Cent. this characteristic difference would still exist. Going a step further, it might perhaps be possible to use such an inherent difference as a measure of durability, those sands having the highest rehydration at 500 degrees or 600 degrees Cent. being long-lived.

As regards the use of dehydration percentages, it was thought likely that the loss of water would be more or less uniformly progressive, from low to high temperatures, since the bond is largely

[10]Studies in the reversibility of the colloidal conditions of soils. Cornell University Experiment Station Memoir, 21, 1919.
[11]Trans. Eng. Ceramic Soc. Vol. 13, 1913-14.
[12]Bull. de l'Academie Imperial des Sciences de St. Petersbourg, VI, Ser. 8, 1909.

composed of hydrated iron, silica and alumina in a colloidal state. If the bond was composed of distinct crystalline minerals, definite critical points would occur where most of the water would be given up, but such is not thought to be the case. So molding sands might be expected to show inherent differences in their amount of dehydration, depending on the heating temperature and the amount and quality of the bond. Thus dehydration also might perhaps be used as a measure of the deterioration of the bond.

With these ideas in mind the following test method was worked out a year ago and dehydration and rehydration factors determined on a few molding sands. However at that time the writer did not have a standard life series to check against, so there was no way of telling whether such a method really gave the comparative durability of the sands.

An electrical oven was made by taking a medium sized tin can, covering it with two thicknesses of the best asbestos paper, and then winding the outside with a heating resistance wire. After being placed in a large tin container, this was surrounded with ten inches of asbestos fluff. By controlling the current with an outside variable resistance, the temperature of the oven was readily held within two degrees of the desired point. With such an arrangement, any temperature from less than 100 degrees to over 700 degrees Cent. could be obtained.

For temperatures up to 500 degrees Cent., a high-temperature precision thermometer was used. Higher temperatures required a platinum-rhodium thermo-couple, which was carefully re-calibrated for this series of heat treatments.

The oven just described is large enough to hold nine porcelain crucibles of 35 grams capacity, and as nearly as could be determined the heat effect was the same on each of these samples, no matter what their position in the oven.

The method of procedure was to take approximately a 25 gram sample of sand and dry it to constant weight at 105 degrees Cent., which usually required about four hours. After cooling in a dessicator, the sample was quickly weighed on a balance accurate to a tenth of a milligram. Then the sample was heated to the desired temperature and held at this point for an hour, after

which it was again cooled in the dessicator and quickly weighed. This loss in weight is the dehydration of the molding sand at that temperature and is expressed in percentage of the original weight.

Sufficient water was then added to the sample so that it was entirely covered and it was allowed to soak for twelve hours. At the end of this period the sample was heated to 105 degrees Cent., to constant weight, which usually required about eight hours, cooled in a dessicator and weighed. The increase in weight is due to the water of rehydration and is expressed as the number of grams on a 100 gram basis.

In order to secure checks on duplicate runs, care must be used to follow the above procedure closely and to weigh the samples quickly as they take up moisture from the atmosphere very readily. It is easier to secure close checks on dehydration runs than it is on the amount of rehydration, as complete equilibrium has not been established during the twelve hour soaking.

After reading the description of this laboratory method the first reaction might be that it is not much of a short-cut. Of course during the periods while the sand is being dried or soaked, no special attention is required. Only the time needed for the different weighings and the one hour heat treatment, require personal attention. So in reality this method is far quicker than that of making successive castings until the sand is burnt out. In addition, only small samples are required, which is often an advantage.

Since nine samples could be heat treated at one time, only eighteen of the entire series of twenty sands were used, samples Nos. 3 and 8 being omitted. Table 13 gives the dehydration percentages of these eighteen sands at four different temperatures and it is clearly brought out that the loss is uniformly progressive, rather than confined to one certain critical temperature. Such a progressive loss would seem to suggest that amorphous rather than crystalline conditions exist in the bonding material.

If we consider this total amount of dehydration at any one temperature, to be controlled by the amount and quality of the bonding material present, perhaps a measure of durability might be given. Of two sands with the same type of bond, the one with

the largest amount of that bond would naturally show the greatest percent of dehydration. Of two sands with the same amount of bond, the sand having the shortest life would show the largest dehydration at the low temperatures.

Table 13

PERCENTAGE LOSS ON IGNITION

Sample	300° C	400° C	500° C	600° C
1	1.08	1.41	2.28	2.83
2	.61	.78	1.15	1.45
4	.24	.27	.52	.72
5	.41	.65	.83	1.44
6	.52	.65	.80	1.32
7	.73	1.02	1.63	1.89
9	.45	.64	.97	1.29
10	.99	1.31	2.19	2.64
11	.78	.95	1.69	2.00
12	1.01	1.56	2.28	2.85
13	.73	.84	1.11	1.52
14	.54	.80	.91	1.09
15	.54	.91	1.14	1.41
16	.93	1.12	1.23	1.90
17	.34	.49	.66	1.23
18	.57	.71	1.28	2.05
19	.39	.58	.96	1.15
20	.71	.82	1.11	1.37

Table 14

PERCENTAGE DEHYDRATION LOSSES AT 300° C AND 600° C AND THE NET LOSS

Sample	300° C	300° C	Average	600° C	600° C	Average	Net Loss
1	1.08	1.12	1.10	2.83	2.82	2.81	1.71
2	.61	.50	.55	1.45	1.43	1.44	.89
4	.24	.22	.23	.72	.72	.72	.49
5	.41	.41	.41	1.44	1.45	1.45	1.01
6	.52	.53	.53	1.32	1.31	1.31	.76
7	.73	.71	.72	1.89	1.92	1.90	1.18
9	.45	.47	.46	1.29	1.32	1.30	.84
10	.99	1.07	1.03	2.64	2.68	2.66	1.63
11	.78	.76	.77	2.00	2.08	2.04	1.27
12	1.01	1.02	1.01	2.85	2.80	2.82	1.81
13	.73	.74	.73	1.52	1.55	1.53	.80
14	.54	.56	.55	1.09	1.13	1.11	.56
15	.54	.59	.56	1.47	1.48	1.46	.90
16	.93	.96	.94	1.90	1.94	1.92	.98
17	.34	.37	.35	1.23	1.37	1.30	.95
18	.57	.56	.56	2.05	2.02	2.03	1.47
19	.39	.43	.41	1.15	1.07	1.11	.70
20	.71	.72	.71	1.37	1.35	1.36	.65

With this in mind, duplicate runs were made at 300 degrees and 600 degrees Cent., which are shown in Table 14. Sands with a short life are considered to have a larger relative loss at 300 degrees Cent. than they would at 600 degrees Cent., so that by obtaining the difference in losses between these two temperatures, the short-lived sands would tend to show a smaller total loss than the long-lived ones. If this is correct we should thus obtain a figure which reflects both the amount and the quality of the bond-

ing material, both of which factors largely control the relative durability of molding sand.

Rehydration tests were also made and it was found that within reasonable limits of heating, this rehydration was a fairly specific figure for each particular sand. Table 15 gives the total rehydration on a 100 gram basis at 300 degrees and 600 degrees Cent., with a check run at 600 degrees Cent.

The amount of rehydration at 300 degrees and 600 degrees Cent. is about the same and the check run at 600 degrees Cent. is

Table 15

AMOUNT OF DEHYDRATION ON A 100 GRAM BASIS

Sample	300° C	600°C	600° C	Average at 600° C
1	.422	.425	.432	.43
2	.206	.236	.216	.22
4	.153	.155	.170	.16
5	.266	.288	.316	.30
6	.302	.325	.337	.33
7	.302	.294	.296	.29
9	.223	.198	.228	.21
10	.196	.253	.258	.25
11	.198	.213	.192	.20
12	.255	.185	.175	.18
13	.252	.217	.220	.22
14	.192	.131	.127	.13
15	.196	.240	.220	.23
16	.221	.219	.228	.22
17	.122	.155	.151	.15
18	.313	.333	.351	.34
19	.138	.171	.174	.17
20	.184	.219	.193	.20

close enough to give a dependable average. The amount of rehydration at 600 degrees Cent. is selected as the basis for a rehydration factor because it more nearly reflects the durability of the sand under adverse foundry conditions.

The total amount of rehydration seemingly depends on the amount and quality of the bonding material, for reasons analogous to those already given above. Since therefore both the dehydration and the rehydration figures are considered as reflecting the same factors—amount and quality of the bond—and since rehydration will counteract to some extent the effect of dehydration, it seemed logical to multiply these related figures so as to secure a life figure. This is done in Table 16 and the result multiplied by 1000 to give whole numbers.

In general the life figures when obtained in this manner and arranged in a series, compare favorably with the standard series,

Table 16

HYDRATION LIFE FACTOR

Sample	Net Loss 300°—600° C	Hydration Factor	Life Factor
1	1.71	.43	735
2	.89	.22	196
4	.49	.16	78
5	1.01	.30	303
6	.78	.33	257
7	1.18	.29	342
9	.84	.21	176
10	1.63	.25	407
11	1.27	.20	254
12	1.81	.18	326
13	.80	.22	176
14	.56	.13	73
15	.90	.23	211
16	.98	.22	215
17	.95	.15	142
18	1.47	.34	500
19	.70	.17	120
20	.65	.20	130

Table 17

Casting Series*	Life Series*	600° F. Series*
1	1	18
12	18	12
18	7	4
17	12	17
11	11	16
13	16	19
7	2	20
2	13	13
20	17	1
16	20	11
19	19	2
4	4	7

*Arranged in order from strong to weak sands.

Table 18

CASTING		HYDRATION	
Sample*	Strength	Sample*	Life-Factor
10	77	1	735
1	54	18	500
12	37	10	407
5	34	12	326
18	30	5	303
6	28	6	257
15	13	11	254
11	out 10th	15	211
13	out 10th	2	196
2	out 9th	13	176
9	out 8th	9	176
20	out 8th	20	130
19	out 6th	19	120
4	out 6th	4	78
14	out 6th	14	73

*Arranged in order from strong to weak sands.

with the exception of Nos. 18, 17, 16 and 7. As far as No. 18 is concerned, its position is not definitely fixed in the standard series as the number of castings made were not sufficient to completely burn it out. In other words, with further heat treatments No. 18 might have moved nearer to the top of the standard series.

At present no explanation can be advanced for the failure of Nos. 7, 16 and 17 to fall into position in the life series. In this connection it might be interesting to point out that the short-cut method of heating the sands to 600 degrees Fahr., and then testing them, did not line up samples 16 or 7 either although No. 17 was brought into position as shown by the comparison of data in Table 17.

Omitting Nos. 17, 16 and 7 Table 18 gives a comparison of the life of fifteen sands as determined by the dehydration and rehydration method, with that determined by the casting method. A similarity in arrangement of the two series is quite evident and it would seem proper to conclude that this laboratory method which emphasizes the hydration of molding sand, merits further investigation.

Summary

In concluding these remarks on the life of molding sands the following points should be emphasized:

1. The amount of the bonding material and the colloidal condition of this material, which includes quality and rehydratability, are the important factors.

2. The suggested casting method of testing the life closely approaches foundry practice and is considered the best means of determining comparative durability.

3. As a rule permeability increases with the heat treatment of the sand due to the formation of compound grains.

4. Of the sands tested, strong Albany has a medium life; weak Albany has a short life; strong Milville has a medium life; all the Lumbertons are short-lived. Newport, Kentucky, and Dansville, Pennsylvania, are longer lived than the corresponding

grades of Albany; Nicked Plate, Ohio, is short-lived, and some of the Virginia sands are long-lived.

5. Compression tests lead to practically the same conclusions as the bar tests, when used on a series of heat-treated sands.

6. Determining comparative durability by heating the sand to 600 degrees Cent. and getting the loss of strength is not a satisfactory method in its present form.

7. Dehydration and rehydration, when carefully determined give a fairly good idea of comparative durability and might be used as a laboratory method.

8. It is to the interest of the foundry industry as a whole, to find out the durabilities of the sands in common use throughout the United States.

DISCUSSION

C. M. NEVIN: We had an interesting discussion yesterday afternoon about the fracturing of quartz grains during pouring temperatures. This common substance we call quartz, it is common enough, but it is not as simple as one would think. For instance, the mineralogist recognizes three or four distinct varieties of quartz. They give some long names to them and, to get real deep, they divide the quartz into alpha, gama and beta An interesting point is that some of this quartz has a very low coefficient of expansion under heat, which is used practically in commercial work, making quartz gas tubes, high temperature measurements and in this pyrex glass, which is supposed to be able to be taken from a hot stove and plunged into cold water without breaking Other varieties of quartz have an appreciable coefficient of expansion, and I am confident such a quartz grain would crack under the heat of a steel casting.

In addition quartz itself has a varied history. In ordinary sea sand the quartz may come from quartz in a granite, a rock of which we make tombstones. It may come from a granite which is an igneous rock, or the silicious part of limestone deposited in the ocean; it may come from a sandstone or a vein material or from quartsite which has been re-crystallized by the heat and pressure and the quartz entirely changed.

The point I wish to leave is that the fracturing of the quartz grains is probable. In brass castings or gray iron castings, it is not very likely. In steel castings with the proper kind of quartz, I think it is very probable

With other varieties of quartz you would not get it. After the grain is fractured, it will fuse more easily than before it is fractured. In addition to the differences in the quartz the history which that quartz has gone through certainly affects the way it stands the heat, or the way it stands the blast. That is the reason some sand breaks down under the sand blast action.

CHAIRMAN BULL: Mr. Nevin has abstracted some very interesting information and on a subject about which a great many of us have thought for a good many years, that is some practical means of guaging the life of sand for a number of purposes, including the possible continual addition to sand to compensate for the deterioration of these same sands. We will be glad to have some discussion on the paper. Mr. Fletcher, it occurs to me to ask if any progress of a nature that will permit application in the foundry has been made in solving this problem in England? Incidentally, we shall be very pleased to hear from you again today as we did yesterday.

J. E. FLETCHER: Needless to say how interesting these two papers are to me. This last paper particularly, seeing that we are busy at the present time in trying to evolve some practical method of finding the comparative life of molding sand. Like the last speaker, I have had to use fairly primitive means of getting information along this line. Our last friend used tin cans. I am afraid my apparatus was not very much more advanced than that. I think it was a common locomotive shovel. At any rate, I started with an apparatus which simply consisted of a fairly hefty shovel and heated my sand to something like a temperature which I thought represented heating conditions when casting. I followed this up, I might say, more scientifically afterwards.

After repeated tests I found some indication of the life of a molding sand. In this case I used a test which some of you may have seen described in a paper I read before the Iron & Steel Institute, a sedimentation test giving a curve showing the range of sedimentation, shaking up by agitated sand. We are really developing along these lines and finding that the colloidal condition of the deteriorated bond gives an index toward the probable life of the sand. I cannot say more than that, as I can not illustrate it very well without a series of curves, for we have found that a series of curves can be determined for each sand which in a very clear way shows the life of the sand; whether you take the ordinary sand heap or as it comes from the quarry's face. I might say that I use that test almost invariably for buying my sand. It has given us such satisfactory indications of the worth of a sand that we use it for buying sand in my own works, and in one or two others.

Scientifically, as far as the British Cast Iron Research Association is concerned, I would not say that we have entered quite into the research stage, but I say that practically that test has given us results. Those

curves are gradually showing us a good deal of the colloidal condition of used sand, and the work of the last speaker will be helpful to us, although I may say that we have gone almost along the same lines of investigation that he has.

I think I hinted yesterday that the difference of the actual grain, the quartzite or other mineralogical type of sand does influence the breaking up of the sand grains. We are also very strongly of the opinion that it is the break up of the grain which is the first index to the probable life of the sand in ordinary use.

Then there is the question of the quality of the bonding material. Your sands, so far as I have examined one or two samples, have not quite the same bonding materials as ours. As I said yesterday, our bonding is highly ferruginous and to some extent very different from yours, and consequently does not deteriorate at the rate that a non-ferruginous bonding sand deteriorates and spoils. Thus we are traveling along two different directions because in that respect our sands are fundamentally different from yours. I have seen that when some of your sands are burned to a certain extent, however, they are in a very similar condition to some of our naturally bonded sands. We find those sands that are highly ferruginous on the outskirts of our coal measures, there where our new red sandstone comes in contact with the coal measure, wherever there is any trace of a volcanic nature in that district there, we come on the molding sand.

I was rather sorry yesterday that nobody followed that very able paper on the geological questions involved in the examination of certain Wisconsin sands. I thought that that was a most useful paper, for we, on our side, are trying to train some of our young foundry students to take an interest in the practical field of geology of their own neighborhood. I understand that some attempt has been made here to do that also.

We find that the geologists in connection with our government department have no knowledge of our foundry requirements. Some of the reports that they have sent out on sand areas have to be gone over by some of us at some little personal inconvenience in order that we might see whether their reports were really of value or not. In many cases we found they were not of much value. In many cases they told us there were molding sand, where we found nothing better than building sand.

I want to stress the point that those who are interested in the subject should find their way into your sand producing districts and delve a little into that very fascinating side of the subject because with a microscope and a very little knowledge it is wonderful what new life is thrown on this problem of molding sand. I thank you for giving me the opportunity of saying these words.

C. M. NEVIN: I am rather sorry that I digressed about the breaking up of those quartz grains because I am afraid I left a rather misleading impression. As a result of this work I have done on the life of molding sand, I do not believe that the loss of life or failure of the sand is due to any destruction of the grain; it is due to destruction of the bond. Steel sand is a different proposition. I am talking about a naturally bonded molding sand. A bond will fail and lose its colloidal properties much quicker than any destruction of the grain and I think it is the destruction of the bond that causes a loss of life and that destruction is due to a change in the colloidal condition.

A. A. GRUBB: It might be well to recall briefly some work that has been done in time past by Mr. Harrington and Mr. Dietert on the durability and try to correlate it with the work Mr. Nevin is doing. If I understand right, Mr. Nevin's work has, in the main, been with the point of measuring the durability of the sand as a whole. The figure which he would get in the end would involve not only the quality of the colloidal material or clay, but also its quantity; so these results, as obtained on a lightly bonded sand would necessarily show that sand up as a less durable sand than a very similar sand containing the same kind of clay but a greater quantity of it. It becomes a question to us on the Test Committee in developing a test for durability, to decide which we are going to be most interested in; are we wanting to know the durability of sand as a whole, or the relative durability of the bonding material.

It would be well, it seems to me if those who are interested in durability, would, wherever possible, apply the test that Mr. Harrington used, the test that Mr. Dietert has employed and the pouring test that Mr. Nevin has employed, and compare the results with the working properties of the sand, so that in the future we will have some actual practical results from which the Sub-Committee on Tests can devise a very useful durability test.

Just briefly, Mr. Harrington's test was this, measure the dye adsorption value of the sand, heat to 600 degrees Fahr. for two hours and measure the dye adsorption again and take the percentage of deterioration. You note that would measure durability of the clay mainly, and it would be a relative durability.

Mr. Dietert took the sand, measured its bond and its optimum water content, heated it to 600 degrees Fahr. for two hours, tempered again to its optimum water content, re-measured the bond and took the percentage of deterioration. I believe that test would take into consideration the quality only, not the quantity, of the clay. If we could make all these tests and then later correlate that data, it would certainly be a great help in arriving at a satisfactory durability test.

H. W. DIETERT: I believe Mr. Nevin misunderstood the result which we wished to obtain from the durability test. The durability test was made for a complete life test. The durability test is practiced to measure the quality of bonding only and not the quality and quantity. I do not believe that if Mr. Nevin was aware of this fact he would have made the remark in his pre-print that the durability test was misleading. The durability test is not misleading if we keep in mind its real purpose. In Mr. Nevin's standard series, sample No. 1, which he claims had the longest life, is the strongest sand of all, namely, 290 by the A. F. A. test. The weakest sand is sample No. 4 and it is only 54 by the A. F. A. strength test. The life of all molding sand takes in a large number of things; it is not only the quality of a clay, but also the retempering. The durability test is no more than punishing your sand. You do the same as you do in the foundry, heat it up in a hurry in an oven and cool it and add water to it and see how it comes back to life, how it takes up water again, then see how much strength you have left. I tested all the clay in the sand. The life test, as mentioned, just tested a little at a time and naturally one of the high per cent, and also the most durable clay came out in the lead.

C. M. NEVIN: I would like to answer that. In my introductory remarks I did not touch on Mr. Dietert's test because I knew he would bring it up, at least I hoped he would. I used Mr. Dietert's method after I had established a series for comparison. This series was established under conditions that were closely allied to the conditions in the foundry. Mr. Dietert's test is a simple test and it is an interesting test. What I wanted to see was whether it would check up with that series, and I am sorry to say that it did not check up with the series. His test has been used and, as he has suggested, I think that it tests not only the quality of the sand but also the quantity. Until he changes his test, I think it is very misleading, because it tests both quality and quantity the way he uses it at present and it did not check with the series of the twenty sands, and therefore I still maintain that it leads to misleading interpretations under its present application.

W. G. REICHERT: I would like to make a few comments on the paper presented by Dr. Nevin. I have run some tests according to Mr. Dietert's methods with revisions. The test sand was also heated to 1900 degrees Fahr. Also, tests were made using green New York fine sand and green Maryland fine sand, continuously using sand in actual molding and recording bond every three times a mold was poured.

These two tests showed conclusively that the New York sand had longer life. Excellent comparative results were obtained by Dietert's method. The reason I determined the bond after heating to 1900 degrees Fahr. was to determine the bond of the burnt out sand and see just what the bond was, this considered as being due to the fineness of the sand.

However, I believe the tests made at 300 degrees Fahr. intervals from 500 to 1900 degrees Fahr. will give us a better idea of the life of molding sand in relation to the temperature at which colloidal material is broken down rapidly. By this I mean where there is a sudden breaking down of the colloidal matter.

C. M. NEVIN: There is one thing Mr. Dietert's test never will do and that is test the sand under anything but oxidizing conditions, and in foundry sand you have both oxidizing and reducing conditions. The sand is black or grey in color, and out from the casting it is red or brown. We know from our study and the heat treatment of clay that clay will go to pieces much quicker under a reducing atmosphere than under an oxidizing atmosphere, so that was another reason why I used the casting method, because I got both conditions more or less as you do in the foundry.

The Geology of Molding Sand Deposits

By David W. Trainer, Jr., Ithaca, N. Y.*

Introduction

It has probably impressed those who have had occasion to examine and compare molding sand deposits of different regions that they not only differ markedly in their nature, extent and form, but that sometimes in the same district or even in the same deposit, differences may be clearly evident.

Although such differences and variations may at first appear somewhat puzzling they are all due to the geologic conditions under which the sand was deposited, and hence are usually explainable.

If now we have some understanding of these conditions, it will be of great assistance not only in prospecting for sand deposits but also in predicting to some extent what variations a given type of deposit is likely to be subjected to, or what the chances are in different regions of finding molding sands.

In the present paper an attempt will be made to point out the causes of variation shown by certain types of deposits, special reference being made to those of Wisconsin and some other states. The consolidated materials such as sandstones, which may be used by the foundry industry after crushing, are excluded.

Types of Molding Sand Deposits

The following rather characteristic types of unconsolidated molding sand deposits may be recognized: (1) Lake deposits, usually of glacial origin, (2) Terrace deposits, (a) along present lines of drainage, (b) along abandoned drainage lines, or (c) of estuarine character, (3) Deposits associated with the terminal moraines of glaciers, (4) Outwash deposits of glacial origin,

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(5) Marine deposits, (6) Deposits along the shores of present lakes, and (7) Deposits of wind blown material.

From the above it will be suspected that many of the molding sand deposits are associated with glacial activity, this being especially true of those found in our northeastern, central, and northern states, for during very recent geologic times, this area was covered by continental glaciers, which formed extensive deposits of material, often of a sandy or loamy nature.

The characters of the several types mentioned above will be briefly described and examples of them quoted.

Lake Deposits, Usually of Glacial Origin

These represent sands which have accumulated in lakes, which in many cases at least were held in by dams of glacial drift, or in some cases by the edge of the glacier forming a temporary dam across the valley in which the lake occurred. Flowing into such a lake were streams carrying sediment that ranged from coarse sand to fine clay. This material was spread over the lake bottom, the coarsest material near the shore, where wave action worked it over into sandy bands or beach deposits, and the finer material farther out. Such deposits when now found, grade from coarse material near the old shore line into finer and finer material towards what was the center of the lake, and may finally pass into clay or fine silt. In other lakes where only fine sand was washed in such a gradation does not of course occur.

A good example of the above is to be seen for instance in the Berlin district of Wisconsin. There the sands occur in the glacial lake Jean Nicolet.[1, 2] This lake, which was formed during glacial times, was held in by a height of land on the south and by ice to the north.

Field study showed that it had three different levels. During each level the waves along the shore formed a beach of coarse material, as we go from this toward the center of the old lake, the sand gets finer.

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[1]Alden, W. C., The Quaternary Geology of Southeastern Wisconsin: U. S. G. S., Prof. Paper 106, p. 395, 1918.
[2]Upham, Warren, Glacial Lake Jean Nicolet: Am. Geologist, vol. 32, p. 330, 1903.

A very interesting relation exists between these different lake levels and the materials which are excavated for foundry purposes. The beach ridges which mark the several lake levels are the core sand producers of the district. The flats between the beaches are the source of the molding sand with the exception of those below the lowest stage which are not producers due to the poor drainage of the lake at this elevation. The flats below the different lake levels on which a great many of the molding sand pits are located show the laminated or banded nature of the deposits which is excellent evidence for the theory that the sands were deposited in the bottom of extinct glacial lakes. Other evidence to support this theory is the variation of clay content shown by a series of sand samples taken in a section from the beach ridge across the lake bottom. It would be quite natural to expect that the sands collected farthest away from the beach ridge would show the highest clay content. The following was found to be true: sand on the beach had a clay content of .74 per cent, two-tenths of a mile from the beach ridge the sand showed a clay content of 4.56 per cent, the molding sand in the second foot below the surface and about one hundred feet further away from the beach ridge than the last sample showed a clay content of 30.66 per cent, and a sample taken twenty-five hundredths of a mile from the beach ridge showed 47.42 per cent of clay substance. The texture of the sands in the above samples varied some from the beach ridge to the lake bottom, the sands on the beach ridge being somewhat coarser.

The molding sands which are found in glacial lake deposits have obtained their bonding material in almost every case by a natural process; that is, the clayey material was deposited simultaneously with the sand grains. This method of formation of the bond in molding sands is distinct from another type which will be mentioned later, and of which the Albany sands are an example.

Terrace Deposits

Along Present Lines of Drainage

In the area affected by continental glaciation the valleys were sometimes occupied by large streams flowing from the edge

of the ice sheet. Such streams often clogged the valley with sediment. It is evident that the material deposited will be coarsest near its source, and become finer and finer as one goes down stream. The finer material being the last deposition as the ice retreated farther and farther to the north. Later, present streams cut through these deposits and the sand remains as terraces.

Sands of this type of occurrence have been described by J. A. Bownocker as occurring in Muskingum County, Ohio. He says in part concerning the origin of these deposits, "Much of the molding sand in this county lies in valleys, and it commonly has pebbles or other coarse material, nearly everywhere it is stratified, and there can be no doubt of its having been transported and deposited by water. Much of the sand, however, lies above the present high water level and it is believed to have been the work of glacial streams. There is strong evidence that the drainage in the vicinity of Zanesville has undergone extensive changes, and before these were made and while they were in progress, the streams had their beds at higher altitudes."[3]

Such deposits are also found along the Wisconsin River in its lower reaches and also along the Chippewa River just south of the City of Eau Claire, Wisconsin. The last deposition on the top of these terraces is quite frequently molding sand where the depositional currents and the material supplied by the stream were of such a nature to give the proper mixture of sand and clay to form a molding sand. Below the molding sand cover there is usually a great thickness of sharp sand and gravel. The "Red Flint" blast sand produced at Eau Claire, Wisconsin, comes from such a terrace. The company operating on this deposit is equipped to excavate the terrace material, and classify it, shipping any grade of sharp sand that may be desired.

Along Abandoned Drainage Lines

Occasionally the streams flowing from the ice, deposited much sand, some of it of value for foundry use, and then at a later date abandoned their channels. Thus at the present day, we

[3]Brownocker, J. A., Muskingum County, Sand and Gravel; Geol. Sur. of Ohio, 4th ser., Bull. 21, p. 341, 1918.

find these filled valleys, with no permanent or persistent stream flowing through them.

This type is best illustrated by the deposits of molding sand found in the vicinity of Mondovie, Wis. Here the sands are found under flat topped terraces along the old course of the Beef or Buffalo River, which at one time flowed west from Mondovie, into the Chippewa River near Durand, Wisconsin, but now its course is southwest from Mondovie to the Mississippi River, at Alma, Wisconsin. This stream diversion may be a case of stream capture or it may have resulted from the damming of the old channel in its lower reaches by glacial material being carried down the Chippewa River.[4] Whatever the case may be, we now find these molding sand terraces above what appears to be an abandoned stream channel.

Deposits of Estuarine Character

In recent geologic time many of our large river valleys which flow into the Atlantic Ocean have been drowned by the sea or in other words have been long narrow arms of it. While the sea has been in these valleys sand and clay have been deposited.

It is rather difficult in many cases to determine exactly whether deposits in river valleys such as the Hudson have had a marine origin or whether deposition took place under fresh water conditions. If the latter is true the deposits in the Hudson Valley are rightfully considered as terraces or of lacustrine origin. There are, however, some that believe that the molding sands in this district as well as the clays may be of marine origin and thus can be considered as estuarine in character.

Deposits of similar origin have been known in the Connecticut Valley, where estuarine conditions existed at one time.

Deposits Associated With Terminal Moraine Material

This type of deposit is not common and is not very easily recognized. The topography of a terminal moraine area is usually

[4]Martin, Lawrence, The Physical Geography of Wisconsin, Wis. Geol. and Nat. Hist. Sur. Bull. 36, pp. 187-188, 1916.

rather rolling in nature and is usually characterized as knob-and kettle topography because it consists of a series of knobs with small closed depressions between them. The molding sand in this type of deposit is usually found on the flanks of the knobs and varies in thickness, showing a greater thickness at the base and grading towards the top of the knob into sharp sand and gravel. These deposits are ordinarily small and change very rapidly in grade and bond strength and require a man of good experience to load from them in order to keep the sand up to a certain grade. The clay bond in these deposits is a natural product of deposition and at places where the clay has not been supplied during deposition a sharp sand results. Illustrations of this type of deposit are found in the morainic areas of southeastern Wisconsin, especially in the area around Bassett, Wisconsin.

Deposits in Terraces of Outwash Material

During the periods that the great ice sheet which partly covered this country during glacial times, remained more or less stationary at its southern limits, great plains of gravelly and sandy material were spread over the country like large aprons by the many streams which were issuing from the melting ice front. This type of deposit is characterized by the flat nature of its topography, and extends southward from a terminal moraine. Such outwash plains may be underlain by nothing but sharp sand and gravel.

In Wisconsin, at least, we occasionally find beds of molding sand immediately under the surface, but they are rarely over 20 inches in thickness.

The bond in the molding sands found in this type of deposit has undoubtedly had a different origin than that attributed to the different types of glacial deposits already mentioned. It has developed by the weathering of the original constituents of the sands since their deposition. This weathering process seems to take place best on these large flat areas and is aided to some extent by a covering of vegetation which furnishes organic acids which help the weathering reactions. These reactions consist of a leaching out of the soluble materials, leaving a residual clay which

coats the grains and fills in the spaces between them. This theory of the origin of the bond in molding sands was first advanced by D. H. Newland[5] and recently applied by C. M. Nevin[6] to some of the sands of the Albany, New York District. The evidence for the theory is twofold. The sand is composed entirely of quartz or chert grains which are very insoluble under ordinary weathering conditions. The grains are coated with a very strong type of clay which does not extend below the zone of weathering or the level of ground water where a sharp sand or gravel is encountered. The clay bond in these deposits has been formed by the weathering of the soluble rock and mineral grains. Very good examples of this type of deposit are found in the extensive outwash flats south of Burlington, Wisconsin. Here the molding sand is very heavily bonded and coarse in grade. This sand is used extensively for heavy castings in the Milwaukee and Chicago foundries.

Marine Deposits

The clayey sands and silica sand formations of the Coastal plain are very important producers and possible sources of molding sand, steel, and core sand. These formations extend along the Atlantic coast from New York to Florida, along the Gulf of Mexico and up the Mississippi River to southern Illinois. It is impossible at this time to mention the names and the geologic ages of all the possible producing formations over this entire area. The formations of the Coastal plain are very changeable in nature, changing vertically and horizontally from sandy to clayey phases. The reason for their irregularity is due to the changing conditions of deposition. Shifting current often played a part so that sandy material was laid down first at one place and then another where at one time the water was agitated so that only sand could settle, at a later date quiet water over the same spot permitted the accumulation of clay.

Fluctuations in land level led to some formations being irregularly eroded while later materials of a different character were

[5]Newland, D. H. Albany Molding Sands, New York, New York State Museum Bull. 187, 1916.
[6]Nevin, C. M. Albany Molding Sands of the Hudson Valley, New York State Museum Bull. 263, pp. 19-25, 1925.

laid down on this uneven surface. Thus the irregular nature of the deposits can be accounted.

The Cretaceous formations of Maryland, for example, are composed principally of red and white clays with the exception of the Raritan formation which is at the base of the Upper Cretaceous. The latter will yield a fair grade of silica sand for steel molding or core work. The production from this formation is very spotted because the sand seems to occur in pockets in the eroded surface of the Patapsco formation which is composed of white clays near its upper surface. The Aquia formation of the Eocene will probably prove to be the best producer of medium grade of molding sand of any of the formations in this section. It has been deposited under rather stable conditions and is quite extensive. The sand from this formation is red to brown in color, has a good bond which is a natural product of deposition. The remaining younger formations with the exception of the three Pleistocene terraces which are known as follows, according to their age from older to younger, the Sunderland formation, the Wicomico formation, and the Talbot formation, are not probable producers. These formations just mentioned have all had a rather varied history which is well reflected as we see them today. They were deposited while the great ice sheet covered the land to the north and west, and large amounts of unsorted material was being brought to sea. This accounts for the very variable nature of the highest and oldest terrace, the Sunderland. It is very gravelly in the vicinity of Baltimore and a few miles to the south, and contains an occasional boulder which was probably dropped from a floating iceberg. Following this formation further to the south the gravelly shore phase is passed and the material becomes quite sandy. Molding sand occurs in this part of the formation, but the occurrences are very irregular due to the rapid nature of the deposition of the material.

The next younger terrace, the Wicomico, seems to be slightly more regular in nature and shows some good molding sand in places. A peculiar relation exists between this formation and the older Sunderland terrace. Where these two are in contact, fair deposits of molding sand seem to occur. The occurrence of

sand at the junction of the two terraces may be explained by the fact that while the land was rising or the sea receding certain actions of the waves or shore currents reworked the material of the older terrace, depositing it at the junction of the two. The author feels that this explains the occurrence of some of the deposits of molding sand in Maryland but does not wish to let this theory account for deposits in any other localities along the Coastal plain which have not been visited.

The Talbot formation, which is the youngest of the Pleistocene group along the western shore of Chesapeake Bay, is worthless as a producer of foundry sand materials. It consists principally of a very irregular mixture of sand, gravel, and silt. A large number of these terraces are very low and marshy and would be very difficult to work if they did contain usable sands.

From this short discussion of the occurrence of molding sands of the Coastal plain of Maryland some idea of the general relations of these deposits may be obtained and also what can be expected of this area as future sources of molding sands.

Deposits Along the Shores of Present Lakes

Many of the large lakes of this country have marked shore currents which are potent factors in sorting unconsolidated materials which are cut away from bluffs along the shore. Lake Michigan is a notable example of this. The bluffs of the lake along the west shore from the northern part of Illinois, north into Wisconsin vary in height from a few feet to almost a hundred feet in the vicinity of Fort Sheridan. These bluffs are composed of glacial materials consisting principally of sand and clay. The waves working on these bluffs sort this material, carrying the clay out into the lake and deposting the sand along the shore. The south moving currents caused by the prevailing northeast winds of this section move the sand south along the shore and large deposits are found piled up on the north side of any natural or artificial obstructions. These deposits are quite frequently dredged up above the water line and allowed to dry and are used in some places for core and blast sand, notably at Sheboygan, Wisconsin.

Deposits of Wind Blown Material

The deposits of this nature may be divided into two classes, those used for molding sands and those used for core work. The deposits used for molding sand are known as loess and are found in the United States in the central Mississippi valley, especially in the states of Iowa, Kansas, and Nebraska, and cover thousands of square miles. The thickness is not usually great, from 10 to 20 feet, but sometimes as much as 100 feet. It is generally supposed that this very fine brown material, which in some cases carries small fossil snail-like shells, has been blown into its present place from the surrounding flat country. The material was originally rock-flour, ground up very finely by the glacier and spread over the country. This material is quite variable, sometimes showing more clayey matter in places and even a great excess of limey material at times. These deposits have been used for stove plate casting at several places, especially at the stove foundries in Quincy, Illinois.

The sands of wind-blown origin used for core work are the dune sands. These are very important in the section along the southern and eastern shore of Lake Michigan, the Cape May district of the Atlantic coast, and other localities. Here the material is thrown upon the shore in the times of storms, dries out during fair weather and is then heaped up by the wind. These deposits are remarkable for their uniformity in grain size. The ones at Cape May are the big core and filter sand producers for the east and those of Michigan for the Middle West.

Summary

It may be said in summarizing this brief paper that the study of the present producing molding and core sand pits from a geological standpoint gives one a better conception of the reasons for the changes in texture and bond strength which are encountered in producing pits, and also it is a great aid in prospecting for new deposits.

Quite frequently the sand producer wishes to prospect for new deposits. If it is possible to obtain a map of the glacial

deposits or a soil map from the state geological survey or agricultural bureau, these will be found of great service after they are studied in connection with known deposits. In the Coastal plain areas, maps of the unconsolidated Coastal plain deposits will be of great help in tracing known deposits across the country to places where they might be accessible to the foundry trade.

Selection and Blending of Core Sands

By A. A. Grubb,* Mansfield, O.

There is much to be gained in the way of better castings, lower costs and increased production by the proper selection and blending of core sands. It is the writer's intention to outline in this paper some of the principles and methods which have aided us in the selection of sands for core work and in the compounding of core sand mixtures for various purposes. While chemical composition is very important in the selection of sands, I shall discuss the problem largely from a physical point of view, only mentioning those compositional constituents which should be especially sought or guarded against.

Working Properties of Core Sand

The primary properties in which the core maker is interested are green bond, dry strength and permeability. It is the green bond that determines how intricate a design he can make, handle and support on a plate for baking without the use of sand beds or metal dryers. It is one of the limiting factors on speed of production. The dry strength determines the fragility or ruggedness of the finished core and consequently the loss which is apt to be incurred between the oven and the mold. The permeability of a core sand determines the venting properties of the cores and in a measure the surface of the castings. While these properties are influenced to a degree by the kind and quantity of binder used, the sand is a very important determining factor.

Maximum green bond, maximum dry strength and maximum permeability are not readily obtainable in one and the same core sand mixture. Sands of high green bond are usually tight and require much binder. It is necessary, therefore, to shape the properties of a core sand mixture to the needs of the work for which it is intended if economy is to be attained. With this point in view a rather extensive study was made of the relation of the

*Director of Laboratories, The Ohio Brass Company.

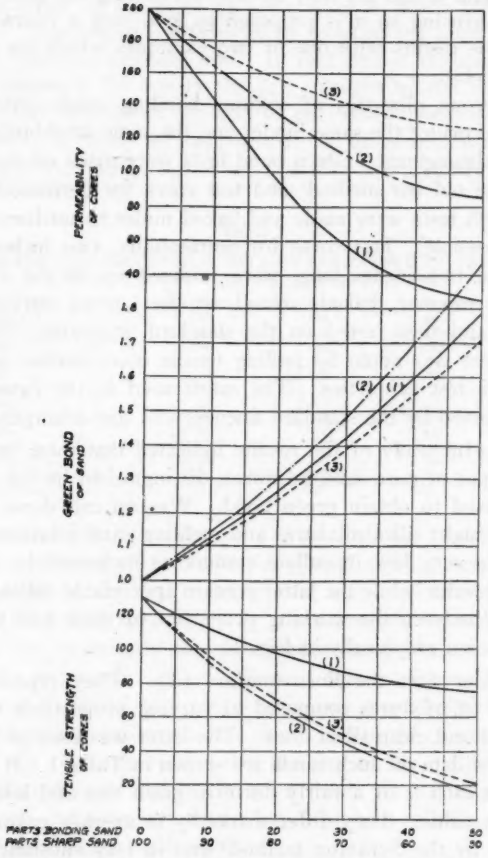

FIG. 1—CURVES SHOWING THE WORKING PROPERTIES OF CORE SAND MIXTURES AND CORES CONTAINING VARIOUS PERCENTAGES AND DIFFERENT TYPES OF BONDING SAND.

texture, clay and colloid content of sands to the physical properties of the core sand mixtures and cores. A presentation of the complete data would not only be time consuming but would probably be confusing so it is proposed to give only a charted summary of the results with one or two examples which are of particular interest.

Numerous mixtures of various bonding sands with sharp sands were made; the same binder and the same sand-binder ratio was used throughout. Green bond tests were made on each mixture by the old bar method[1] and test cores for permeability and dry strength tests were made and baked under as uniform conditions as possible. Test cores for permeability, two inches in diameter and two inches long, were rammed up on the standard A. F. A. rammer, baked, coated on the curved surface with paraffine, and then tested on the standard apparatus. The dry strength test was made by pulling tensile cores similar in shape to concrete test briquettes. The sands used in the experiments were examined by the standard fineness and dye adsorption tests.

A careful study of the results indicated that there were two general types of core sand mixtures, distinguished by the kind of material used to obtain green bond. We can call these for the present straight silica mixtures and molding sand mixtures. The former are very low in colloid content as measured by the dye adsorption value while the latter contain appreciable colloids. The difference between the working properties of these two types of sand is shown graphically in Fig. 1.

Consider first the lines marked (1). They represent the properties of mixtures composed of varying proportions of clean sharp sand and clean silica flour. The latter was used as bonding sand. Test data on such sands are shown in Table 1. It is to be noted that each is of a fairly uniform grain size and low in dye adsorption value. They differ markedly in average grain size as calculated by the Scranton method[2] and in clay substance. The percent of clay substance in the silica flour is very high but this material is merely finely divided silica, probably only slightly smaller than the particles in the —270 or pan material and is not

[1]Wolf and Grubb, Lab. Testing of Sands, Cores and Core Binders, Proc. A. I. M. E., 1920.
[2]See Ries and Rosen, Mich. Geol. Survey, 1907, page 49.

of a colloidal nature; this is indicated by the low dye adsorption value.

The effect of additions of silica flour to sharp sand is very marked. It produces a higher green bond in the sand making it easier to work on intricate jobs. In fact almost any desired bond can be obtained. It lowers the dry strength of the cores, however, so that for a given strength of core more binder would have to be used. It closes up the pores of the cores somewhat so care would have to be exercised to see that they are properly vented.

Table 1

FINENESS AND DYE ADSORPTION DATA ON SANDS USED IN EXPERIMENTS THE RESULTS OF WHICH ARE SHOWN IN FIG. 1

	Silica Flour	Lake Sand	Molding Sand	
On 6 mesh	.00	.00	.00	.00
On 12 mesh	.00	.00	.00	.00
On 20 mesh	.00	.08	.00	.21
On 40 mesh	.02	1.44	1.44	2.79
On 70 mesh	.10	60.39	5.46	24.30
On 100 mesh	.16	34.88	27.10	25.28
On 140 mesh	.27	2.51	28.42	17.92
On 200 mesh	3.25	.32	12.98	11.80
On 270 mesh	4.89	.04	9.40	3.91
On —270 mesh	52.69	.04	5.40	4.80
Clay substance	38.62	.30	9.80	8.99
Average mesh of grain	256	52	112	91
Dye Adsorption	46	22	404	367

Now consider line (2) and (3) of Fig. 1. These represent mixtures composed of the same sharp sand and the same quantity of linseed oil binder, but molding sand was used to obtain green bond,—(2) a fine sand and (3) a coarser one. With molding sand we get practically the same green bond but the cores are more open and much weaker. The test data on the molding sands (see Table 1) show an average grain size much larger than that of the silica flour and much less clay. Hence the greater permeability of the resulting cores. But the clay of the molding sand is quite different from that of the silica flour. It not only carries a higher iron and alumina content but is high in colloids as is indicated by the dye adsorption value.

Comparative Properties

Straight silica sands in general require less binder to produce a given strength of core than do molding sand mixtures. This is particularly true of oil binders and in a less degree of water sol-

uble binders. This difference in binder requirements is very important because oil binders usually represent from a quarter to a half of the cost of a core sand mixture. The straight silica sands are somewhat harsher to the feel than molding sand mixtures. They yield less under pressure, are less plastic. As a result over ramming is less apt to produce tight cores and differences in temper effect the hardness and permeability of the cores to a less degree. The cores seem to be a little more brittle while in the green state and so are subject to fracture or other damage just a little more than are those made from a molding sand mixture of the same green bond.

The straight silica cores are usually removed from castings more readily than those made from mixtures containing clay. Clay is a good bonding agent but it does not break down when struck by the heat of the molten metal. Instead it fuses into brick-like material and makes the core difficult to remove.

Certain advantages are gained, however, by the use of molding sand or small percentages of colloidal clay in core sand mixtures. Such mixtures afford maximum permeability for a given bond. In other words they are adapted to jobs which must be very open and yet cannot be made from sands of low bond. This happy combination of properties is due to the fact that the needed green bond is obtained by coating the large grains of the sharp sand with a quantity of very sticky colloidal clay which is small in comparison with the amount of non-colloidal but fine material which would be required to produce the same bond. The pores are thus left more open. Such clay, however, absorbs oil to a remarkable extent, hence extra binder is required.

In order to obtain the properties of a molding sand mixture it is not necessary to actually add molding sand or sticky clay. Many bank sands sold as core sands carry enough colloidal clay to give them these properties in a degree. Unfortunately the first of these properties to become evident is the oil absorbing characteristic which frequently makes them expensive to use. Furthermore it is almost impossible to remove all this clay by artificial washing. A part of it seems to be tied firmly to the grain and only the forces of nature by long continued grinding and washing can remove it. On the other hand a considerable percentage of

clay substance as measured by the standard A. F. A. test does not necessarily indicate that a sand has the properties of a molding sand mixture. The dye adsorption test seems to be the only practical test we have available for measuring this important property.[8] By measuring the colloid content of clay it not only measures the sticking or bonding quality of that clay but it affords an index of its oil absorbing properties. Of sands similar in grain size and containing equal quantities of clay, those which have high dye adsorption values not only have a higher green bond strength but require more oil to bind them.

Table 2

	Bank Sand		Lake
Sand Data:	Raw	Washed	
Average mesh of grain	50.3	46.8	52.3
Clay Substance (Per cent)	1.04	0.40	0.80
Dye Adsorption	119.0	74.0	22.0
Core Tests:			
Sharp Sand (Parts)	80	80	80
Silica Flour (Parts)	20	20	20
Oil (Parts)	2	2	2
Green Bond	1.52	1.30	1.36
Permeability of Cores	106	98	102
Strength of Cores	84	97	147

Recently a bank sand very similar in grain size to a lake sand used for oil bound cores was offered as a substitute. Two grades were offered, one raw as it came from the bank and the other thoroughly washed. The prices were very attractive so comparative tests were made. This data is given in Table 2.

The strength of the baked cores is in reverse order to the dye adsorption values. A half more oil would be required to produce from the washed bank sand as strong a core as that produced from the lake sand by two parts of oil. Complete cost calculations show that, although the bank sand could be laid down at the plant for a dollar less per ton than lake sand, the additional oil required to bind it would more than offset this difference and would entail a loss of some forty cents per ton.

Similar tests show that the white silica sands from the region of Ottawa, Illinois, which have very low dye adsorption values, require still less oil to bind them than do the lake sands. They are, therefore, very desirable for oil bound cores provided the cost does not offset the saving in binder.

[8] H. M. Lane, The Core Room: Its Equipment and Management. Trans. A. S. M. E., Vol. 30, p. 776.

In case it is found necessary to use the more open but higher bonded molding sand mixtures which ordinarily are great oil absorbers, conditions may permit the use of the cheaper water-soluble binders or part water-soluble and part oil. The difference in binder requirements are then not so pronounced nor are they so expensive. It is not within the scope of this paper to discuss the conditions under which such binders prove satisfactory; this phase of the problem, however, is a most fruitful one for investigation.

The benefits to be gained by proper selection and blending of core sands are very real. The writer has record of a case where molding sand costing $3.00 per ton was replaced with a silica wash costing $6.50 per ton, in an oil bound sand. The change actually netted a reduction of 10 per cent in the cost of the core sand mixture due to saving in binder and reduced the labor of knocking out the cores more than 50 per cent. In another case a blended sand mixture containing molding sand was replaced by a straight bank sand which carried the desired grain and clay content; the change in this case netted a saving of seventy cents per ton or $12.00 per average working day.

The problem of selecting and blending core sands is not a simple one. It presupposes a knowledge of the requirements involved in making and handling the green core, in handling the baked core, in getting a perfect casting over the core and finally in getting the core out of the casting. Frequently it involves balancing one property against another and choosing that mixture which will give best results at reasonable cost. Thorough knowledge of the sand characteristics, however, enables one to arrive most definitely at the proper mixture with the least trouble and delay.

DISCUSSION

CHAIRMAN R. A. BULL: Mr. Grubb, wherever you use the word silica wash in your paper, you mean, of course, silica flour, as it is purchased in commercial form?

A. A. GRUBB: Yes, sir.

CHAIRMAN BULL: This is a very interesting paper, gentlemen; brief it is true, but indicating a very important element in the economy, in the satisfactory production of castings that require cores.

H. W. DIETERT: I would like to ask Mr. Grubb whether he has a curve showing relation between strength of cores and dye adsorption. I firmly believe myself that dye adsorption is very valuable in determining the quality of core sand, and would like to know just how much experimental work he has done on this, so that we won't have to duplicate it.

A. A. GRUBB: I have not plotted dye adsorption against strength of cores directly. Those curves on page 809, however, bring out the relation very definitely. We have maintained there practically a constant green bond, which, after all, is the working property we seek, then we obtained radically different strengths which are shown in the difference between line one, at the foot of the page and lines two and three. By taking a great number of sands and plotting dye adsorption, against strength, the relation can be shown very definitely, while we have plotted, I would say, at least two or three dozen sands, which we have examined with the intention possibly of substituting them for the sand we were using, I have never plotted them in the relation Mr. Dietert suggests. Such a thing would be valuable indeed.

CHAIRMAN BULL: I wonder if Mr. Saunders does not have some information on that point that he would be willing to give us?

W. M. SAUNDERS: I have not, but I would like to mention a point about the crystal violet dye used in the dye absorption test. Considerable trouble has been found in using dyes in laboratories where dyes from different manufacturers have been used. That is one trouble the committee has been trying to eliminate by getting one standard dye. At the present time there is a dye called the pure dye, manufactured by the Dupont people, which is very suitable for this dye test, so that I would advise any of you who are going to start making these dye tests to purchase the pure dye from the Dupont people. It is not very expensive; I think it is about $3.85 a pound, and a pound would last for years.

CHAIRMAN BULL: It is quite evident from the last remarks that Mr. Saunders is not commissioned by the Dupont people to try to sell dye if $3.85 worth would last for years; it would not be an unethical procedure to mention it.

R. F. HARRINGTON: Just a word on the question of the dye. I thought Mr. Saunders might be a little more explicit. If I recall correctly, we had considerable trouble in our own laboratory in purchasing the material from the Dupont company because of the fact that there were several lots of what was supposed to be the same dye, that is, crystal violet dye, and lot F, E and D. I wonder if Mr. Saunders could not go a little more into detail to make sure that the men get the particular lot he has reference to?

W. M. SAUNDERS: I can only say that this pure dye is a recent product which they have developed. Of course, you all know dyes are filled with dextrine and various other things and the dye Mr. Harrington

refers to only tests about 80 per cent of this pure dye. I understand the Duponts are not going to make any more of the old form of dye, but only the pure, so if you get the latest product not any letter brand, but just the pure dye, I think you will get the full strength dye. This product has only been issued within a few months.

P. W. CRANE: This is not a direct discussion of Mr. Grubb's paper, but something which came to my mind while these very splendid papers were being presented, on the application of the A.F.A. tests to the foundry. As you know, there is a little pamphlet published by the American Foundrymen's Association which gives the test method of permeability, cohesiveness and fineness and also the supplementary tests for dye adsorption and chemical analysis.

As I stated yesterday, in our investigation of Ohio sand we have visited quite a few foundries and in three of these foundries—I can say this definitely as to three of them and make the statement rather indefinitely for a good many more—they have either purchased or in some way obtained this pamphlet of the A.F.A. test and have read it through, have not seen its application to their foundry and have just discarded the idea. In other words, they did not have enough imagination to see how these tests could be applied to their foundry, and it took considerable talking on our part to convince them that these tests were worth while and could be applied to their work. In this connection I wonder whether men such as Mr. Dietert, Mr. Grubb and Mr. Harrington, who have had a great deal of experience applying tests to their particular foundries, could not perhaps write an additional chapter to this pamphlet which would simply give a general method of attack for applying these tests to foundries in general? Of course, Mr. Grubb said that each foundry will have to apply them a little differently, but if they could simply write a general discussion of the subject which would get the foundries interested enough to apply the test to their sand heaps, the foundries would soon work out the method by which the tests would be applied for their particular kind of work. I want to suggest this for the benefit of the foundrymen who are not fortunate enough to come to these sand meetings and hear such men as Mr. Dietert and Mr. Grubb present their papers.

J. H. HALL: I am a steel metallurgist, and it seems to me that the most important thing I have seen or heard at this whole meeting is this sand session. I am very sure that the men of my company who ought to be here are out there looking at the molding machines that have been seen for ten years and I wish very much that the next time I come here with them the sessions will be heavily advertised to get it through their heads that here is where they belong

CHAIRMAN BULL: This is a very interesting tribute to the practical value of the subject that brought us here this afternoon.

Methods of Testing Core Sand Mixtures

By J. Fletcher Harper* and W. J. Stevenson,* Milwaukee, Wis.

It is obvious, from a study of articles published on foundry sands and the testing of them, that particular efforts have been centered on molding sand mixtures and their testing. However, up to the present, the authors have been unable to find any definite record of a standard method of testing core sand mixture so as to get definite and unbiased test results from which a fair comparison can be drawn of the value and merits of the different kinds of core sands and binders. This condition is possibly due to the various manufacturers of core binders being ever ready to present their aid in the furtherance of their particular binder and to the requirements of their particular customer, thus making any results an individual service, rather than an actual comparison for binders.

It appears that there is considerable opportunity to show a saving in dollars in foundry costs if more attention is given to the testing of core sand mixtures; and that the results of such tests will show whether or not a certain kind of core sand mixture is correctly suitable for a core that is to be used in any definite place.

The Allis-Chalmers Manufacturing company has endeavored to adopt a standard method in experimental testing work that will give an unbiased result as to the merits of core sand and core sand binders.

Having the equipment for testing sands as has been recommended by the Joint Committee on Molding Sand Research, it was natural to look to this equipment to provide a means for getting the core test results. By the use of this apparatus and some minor additions, it has been possible to make some tests for strength and permeability of cores, by which a comparison of different core sand mixtures can be made.

One of the principal requirements of core sand mixtures is strength (when baked dry) to sustain the resistance of the flow of molten metal, also the pressure of the metal and gases. In

*Research Dept., Mfg. Dept., Allis Chalmers Mfg. Co.

order to measure this quality of strength (when baked dry) the transverse test appears to offer the best means of comparison.

Transverse Test

Using the core box that is required in making up a test piece for the Doty cohesiveness test, a core test piece is made in the following manner:

In assembling the core box, the same as in the test for molding sand, the bottom plate is covered with a strip of empire cloth. This empire cloth is made of one thickness of cambric cloth that has been coated with a baking varnish, the total thickness of which is .005 of an inch. This cloth is flexible, strong and moisture-proof and will not absorb any of the moisture or oil from the sand, and can be used over and over again. Sheet rubber could undoubtedly be used with equal success. Waxed and oiled papers were tried, but they are not as satisfactory and it was always found that after ramming the sand, the paper showed some evidence of moisture absorption.

Omitting the use of the riddle, the sand mixture is spread into the core box by sifting or rubbing through the hands. Because of the nature of the mixtures tested, the use of the riddle was omitted. When using a heavily bonded sand, the passing of it through the riddle tends to classify as to a certain size mesh, keeping out of the test some of the larger particles, that would ordinarily be used by the foundryman in making up a core. Thus the test would not show a result of the sand as the foundryman is actually using it, but as the sand has been re-created and classified. Judgment must be used to see that the particles used in the test piece are not entirely out of proportion to the size of the test piece and to the kind of sand mixture being tested. The sifting or rubbing the sand through the hands enables the larger particles to be detected. As only one size mesh riddle is furnished in the standard test outfit, and as the riddle is not applicable to all mixtures of sand, its use has consequently been omitted in all of these tests.

The sand is leveled off in the core box by the use of the strikes and the sides squeezed together and held in place. A 2 inches wide piece of varnished cambric or empire cloth is placed

on top of the sand. This is done to prevent the core sand from sticking to the trussed wooden rammer block.

The core box thus filled is placed in the ramming machine, and the trussed rammer block is put on and placed level on the sand by the use of a small spirit level. The trussed rammer block is leveled in all tests, as more uniform tests result by this practice. The sand is leveled in the box by the use of the strikes; but after the sides have been squeezed together, to form the 2 inches dimension, it is found that the sand forms a ridge or hump along the center of the specimen, and that it is quite difficult to set the heavy rammer block level, both ways, on top of this ridge. The trussed rammer block should be level to receive the first blow from the falling weight; if not, it will tend to thrust in the direction the block is canted. The weight is dropped three times on the specimen, the same as is done with the molding sand test, so that the specimen when thus rammed is 1 inch thick by 2 inches wide by 16¾ inches long. Dropping the weight three times gives a uniform test result.

The rammed specimen with the bottom plate is removed from the core box and the specimen transferred to a flat steel plate, by rolling over. The core test piece is then placed in an oven and baked at a temperature as may be required for the kind of binder that the core sand mixture contains. After baking correctly and the test piece allowed to cool, it is sawed into two equal parts, making test pieces 8⅜ inches long. (The test piece is sawed in two so as to avoid any strain or jar being transmitted to the portion of the piece that is not under the test and which might affect the results of the test when that portion was placed under test.)

The apparatus used for testing this 1 inch by 2 inches by 8⅜ inches test piece is shown in Fig. 1 and is made as follows: A piece of board 1¼ inches thick by 4 inches wide by 27 inches long is used and at the center portion of the board are fastened two strips of 1½ inches angle iron, the width of the board. The angle iron is placed with the apex of the angle up, thus making two "knife edges." (The knife edges should be broken with a file if too sharp.) These angle iron pieces or knife edges are spaced parallel at 8 inch centers. (This 8 inch dimension was used for convenience as the cohesiveness test piece being 16¾ inches long,

when cut in half gives two test pieces 8⅜ inches long from the same bar. The 8 inch length makes a fair size test piece and, although the test piece is only 8⅜ inches long the tests have never failed due to this dimension being too short.)

On the board are drawn the lengthwise center line and also the crosswise center line between the two knife edges. The pressure is applied through a yoke, the upper parallel being a

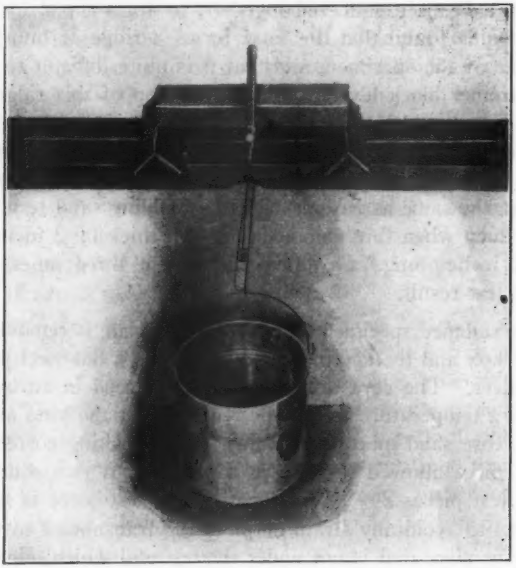

FIG. 1—METHOD OF TESTING FOR TRANSVERSE STRENGTH

metal rod ⅜ of an inch in diameter by 8 inches long. This rod also has a line drawn around it at the center and two wire connectors at each end at a distance of 3½ inches from the center. The lower parallel of the yoke has a hook at the center for a pail to apply the breaking weight. A pail, some dry sand, and two supports for the board, such as two stools of equal height, are all that are required for the test.

The board is placed with the knife edges up, spanned between two supports. With the aid of the lengthwise center line drawn on the board, the core test piece should be placed centrally

across the knife edges. Then with the aid of the center lines on the board and on the rod, the rod should be placed squarely and centrally across the top of test piece. The pail is then suspended from the center of the lower parallel of the yoke. Dry sand is then poured slowly into the pail until the core test piece breaks under the weight of the sand. The pail and sand are then weighed, which result gives the breaking strength in pounds. This value in pounds is an excellent check on the comparative strength of cores; and if desired the modulus of rupture in crossbending can be figured in pounds per square inch.

However, this value of modulus of rupture in pounds per square inch is only a fictitious value and should only be used as a comparative value of the strength of the material when loaded as a beam; and because of the non-elastic properties of the material and unknown distribution of stress in the material, no comparison or relation can be established between either the tensile or compressive strength.

The beam formula is:

R—Modulus of rupture in cross breaking in pounds per square inch
P—Breaking strength in pounds
b—Breadth of bar
h—Height of bar
l—Length between supports

$$R = \frac{3\ lP}{2\ bh^2} \text{ or } R = \frac{3 \times 8 \times P}{2 \times 2 \times 1} \text{ or } R = 6P$$

Permeability Test

Permeability of core sand is an important factor which should be known by a definite value in obtaining the merits and quality of core sand mixtures and binders. For simplicity the standard A. F. A. sand testing apparatus for giving permeability values should be used for core sand.

The permeability of the core sand, after it has been properly baked as in actual core making practice, should be the correct permeability value to know; as it has not a direct relation to the unbaked permeability. Therefore, the permeability should be taken after the test sample has been thus baked.

If a test piece for the permeability device is made up and baked, it, due to the changes in size, will not fit in the brass tube and therefore such a test will not be accurate or reliable. To receive any reading, the test piece would have to be sealed into the brass tube so that all the air from the permeability device would have to pass through the sand.

Any method of sealing the tube is unreliable, due to the fact that it is difficult to be sure that the test sample is thoroughly sealed in the tube. Therefore a method has been devised which omits the sealing of the test piece in the tube, and still gives the same permeability value, by means of an appliance to be used with the regular permeability apparatus.

This appliance as shown in Fig. 2 was made as follows: A brass tube the same dimension as the regular brass tube for holding the permeability test piece, that has inside diameter 2 by 5 inches long, is used. In this brass tube is sealed a wooden plug 2 inches in diameter by 3 inches long. This gives an air chamber or space 2 inches in diameter by 2 inches long at one end of the tube, the same condition as would exist if a rammed specimen were in the tube. Through the center of this wooden plug is drilled a $\frac{9}{16}$ of an inch hole and into which is sealed a piece of rubber tubing 16 inches long and having an inside diameter of $\frac{25}{64}$ of an inch.

Into this rubber tube is fitted a glass tube having an inside diameter of $\frac{3}{8}$ of an inch at one end and the other end drawn out taper so as to give an orifice opening of 4.1 millimeters in diameter one way and 3.8 millimeters in diameter at right angles to the preceding dimension given. The total length of the glass tube is 5 inches. Over the orifice end of the glass tube is another rubber tube, $\frac{3}{16}$ of an inch diameter inside and $3\frac{1}{2}$ inches long. The other end of this latter rubber tube is sealed into the top of a standard nursing bottle nipple, which is dome-shaped or semi-spherical, having a $1\frac{3}{4}$ inch diameter opening.

From different tests which we have made, the length dimensions of the parts have no particular value as they have been varied without any effect in the results. It would appear that the only variable by thus changing, would be in the length of time for the manometer to reach its maximum pressure.

Test Procedure

The test procedure is as follows: Using the rammer and tube for making the standard A. F. A. permeability test piece, a specimen is rammed by dropping the rammer weight three times as in the method for testing molding sand. The specimen thus rammed

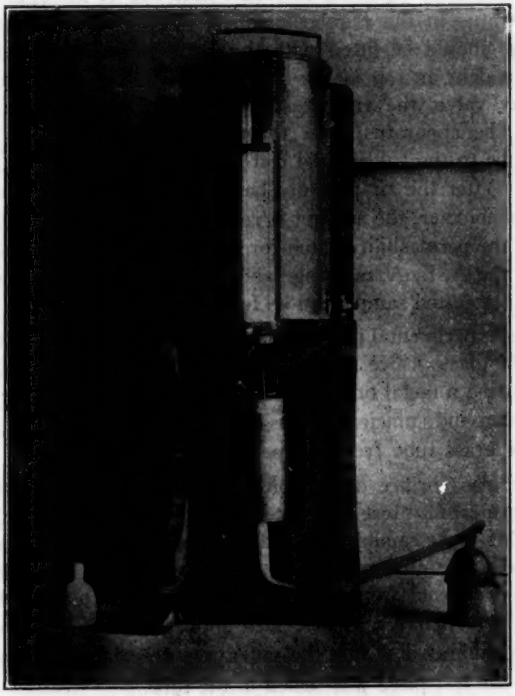

FIG. 2—METHOD OF TESTING PERMEABILITY

to within the regular tolerance marks is slid out of the brass tube onto an iron plate and put into an oven to be baked at the proper temperature.

After the test piece is removed from the oven and cooled, a thin rubber tube is stretched over the test piece. (This thin rubber tube is made from a section cut from a toy rubber balloon.)

The object is to have the rubber fit snugly around the test piece leaving both ends open so that air being forced through the test piece will have to pass through its entire length. Over one end of the test piece thus enclosed in the thin rubber tube, is stretched the rubber nipple of the permeability appliance.

The test thus assembled is ready to be placed in the permeability testing machine, by placing the brass tube end of the appliance in the apparatus in the regular manner. The permeability testing apparatus should be fitted with the large orifice plate using the 10 c. c. weight on top of the tank for pressure. By opening the three-way valve, the air pressure is applied through the orifice plate in the apparatus, thus through the appliance and second orifice tube to the baked sand test specimen at the end of the appliance. After the air pressure has become constant as indicated by the manometer, the amount is recorded. Referring to the table showing the permeability value for corresponding test pressures as given in the A. F. A. molding sand tests tables,* the permeability value of the tested sample can be found.

This experimental permeability appliance is admittedly delicate due to the glass orifice, and no doubt could be made just as satisfactory using a metal orifice. The 16 inch long rubber tube allows convenience and sufficient radius to change test pieces and not remove the brass tube from the permeability machine.

The glass orifice dimensions were obtained as follows: A baked permeability test piece was sealed with the greatest care in the regular brass ramming tube and put in the permeability apparatus and a certain pressure reading was found. This same test piece was removed from the brass tube and after placing it in the permeability appliance as described above, the orifice in the glass tube was calibrated so that the same pressure reading was secured as when the test piece was sealed in the tube.

Test Results

To check this result further some damp clay (rammed a sufficient number of times to be sure it could be handled without damage when removed from the brass tube), was put in the appliance. The damp clay was used so as to get a moisture seal in the tube

*Tentatively adopted methods of tests. A. F. A., June 1, 1924, p. 53.

the same as in a molding sand testing. One of these results is as follows:

Pressure reading when in brass tube.....9.64
Pressure reading when transferred to appliance....9.64

From these pressure readings it is evident that the permeability appliance is safely conveying all of the air pressure through the test piece and also the size of the glass orifice makes the appliance check the standard method tests, which would indicate that the standard A. F. A. permeability value table as mentioned above could be used with this appliance.

Further check tests were made, a representative result is indicated in Table 1. A test piece was made up as described above from a core sand mixture and rammed with permeability rammer three times and baked in an oven.

Table 1

Method of Test	Test Piece Sealed in Tube with Paraffine Manometer		Same Test Piece Placed in Permeability Appliance Manometer	
	Time	Pressure Reading	Time	Pressure Reading
With large standard orifice and 10 CC weight on tank		4.7		4.7
Ditto with no weight		2.1		2.1
No orifice and no weight, Standard A. F. A. Test	27.23	2.1	27.23	2.1

Table 2

In this test the same test piece used in both baked and unbaked condition.	Rammer Weight Dropped 1 Time		Rammer Weight Dropped 2 Times		Rammer Weight Dropped 3 Times	
	"A" Sample	"B" Sample	"A" Sample	"B" Sample	"A" Sample	"B" Sample
Permeability Pressure Unbaked	5.4	5.6	6.8	6.4	7.4	7.4
Permeability Pressure Baked (Using Permeability Appliance)	4.4	4.5	5.5	5.2	5.8	5.8

The practice of ramming the specimen three times was adopted because it is the standard method in the molding sand testing, and also it was found that ramming three times gives more uniform results, as noted in Table 2.

The ramming of the test specimen three times of course produces a tighter and more dense piece than a core made from the same core sand mixture and, therefore, it does not give an actual result of the working condition. However, if all tests are made with the same density of ramming it affords a reliable means of

comparison of permeability qualities of different cores and mixtures, and, as mentioned before, it maintains the standard methods adopted in molding sand testing.

The test of Table 3 shows the effect of moisture on the permeability of core sand mixture; in other words, the moisture content of the core sand mixture changes the quality of the sand even though it is ultimately all baked out. In this test, all samples were made up of the same kind of sand and baked at the same time in an oven.

In all tests made this permeability appliance was found reliable and indicative of any change in core sand mixtures. The appliance is inexpensive to make and all parts can be used over and over again.

Summary

It would appear that the green or unbaked strength of core sands should be determined by means of the Doty cohesiveness test and the baked strength by means of the transverse test as outlined above. The transverse test has proved an excellent method

Table 3

Test Methods	Moisture 7.1 Per cent		Moisture 9.4 Per cent		Moisture 11.2 Per cent	
	A.	B.	A.	B.	A.	B.
Permeability Pressure Reading Unbaked (Standard A. F. A. Method)	7.0	7.1	8.3	8.4	9.1	9.2
Ditto Baked (Test made using Permeability Appliance)	5.4	5.5	6.4	7.2	7.4	7.5

of comparison and it lends itself to easy operation without a large number of testing variables. The tensile strength test is difficult to make, the test pieces difficult to uniformly ram, and the shape of the test piece to use, a very debatable question. Further the tensile strength of a sand mixture is its minimum value; and a core is practically never used in tension.

The compressive strength is probably the most representative value as regards to the actual operating conditions of cores. However, the degrees of experimental or testing errors are great and the results are consequently most erratic. The size of the specimen, its shape, the degree of fineness of sand, the presence of large

particles, the surface of the compression faces, and the percentage of bearing of these faces, all tend to vary the compression results. The use of the compression test was discarded in favor of the transverse test because of these differences in testing.

The unbaked permeability should be made in the manner as prescribed in the A. F. A. tests for molding sands, and the baked permeability should be determined as outlined above. Extreme care should be used in making all permeability tests on wet sands to see that after the sand has been rammed in the tube, that the tube is handled very carefully, especially avoiding any jar when removing it from the ramming machine, or when placing it in the permeability apparatus. A slight jar to the tube is very liable to break the moisture seal of the sand to the tube, causing air leakage and a false permeability reading.

The percentage of moisture, or rather "the percentage volatile" should be obtained and the strength and permeability found as of this value. A series of tests should be made covering variations in this "percentage of volatile" and that percentage used which gives the best strength and permeability figure for the mixture.

References

1. Pat Dwyer, Set core mixture standards, The Foundry Sept. 7, 1922, Vol. 50, No. 17.

2. C. S. Koch, Core Mixtures for Light Steel Castings, Trans. A. F. A., Vol: 30 (1923), pp. 236-256.

3. A. Campion and J. McEachen, Oil Sand Cores and Binders, Proceedings Institute of British Foundrymen, 1923.

4. C. A. Hansen, The Physical Properties of Foundry Sands, Trans. A. F. A., Vol. 32, Part 2 (1924), pp. 57-97.

5. H. W. Dietert, Commercial Application of Molding Sand Testing, Trans. A. F. A., Vol. 32, Part 2 (1924), pp. 24-44.

DISCUSSION

R. E. KENNEDY: Mr. Grubb in his work on core testing has, I believe, coated his test cores with parafine instead of using the rubber cover as described by Mr. Harper. I wish to ask Mr. Grubb to discuss this point.

A. A. GRUBB: In the tests that were reported in the paper presented a moment ago we used the same two-inch cores that Mr. Harper used. We have a brass cylinder which, at one end, fits on the stopper of the standard A.F.A. permeability apparatus. That flares slightly in diameter so that the two-inch core will fit into it rather snugly. We melt paraffine to just above its melting point, not hotter, and dip the core into it two-thirds of its length, then clean the sand, slip this end into the clean brass tube, dip the whole into the molten paraffine up over the joint between the core and the tube, which seals the entire outfit on the permeability apparatus. Then we turn on the air. If it shows a zero flow of air, we immediately know that it is sealed entirely and then we clean the end of the core, turn on the air again and take the permeability reading. We find it very satisfactory.

CHAIRMAN BULL: Do you often find a leakage on the first test, or what is the proportion?

A. A. GRUBB: If the paraffine is too cold, it sometimes does not cover completely and that test will show it up immediately. It has this advantage that it gives you a check on every determination to see that you have it properly sealed.

J. F. HARPER: I might say in that respect, Mr. Grubb, that on fine core sand the paraffine or air seal we use, which consisted of a heavy varnish, is quite successful, but with the coarser mixtures, we found that the penetration was sometimes as high as nearly one-third of the core and in those cases our reading was decidedly faulty. Such results were what caused us to turn to this easily stretched balloon method.

CHAIRMAN BULL: That is a point which is most interesting; that the paraffine itself changed the characteristics of the core.

A. A. GRUBB: By using a thermometer with a stirring rod in our paraffine and holding the temperature between 130 and 140 degrees for the paraffine we were using, I believe that difficulty can be entirely prevented. We have used coarse sand with permeability as high as three or four hundred and I believe six hundred and the paraffine peels off without tearing. If it does not peel off, it becomes readily evident to the eye that it has penetrated too deep.

Molding Sand Work at the University of Cincinnati

By P. W. Crane,* Cincinnati, Ohio.

General Statement

The Commercial Club of Cincinnati Resource Survey was organized for the purpose of making an investigation of the raw materials originating within the territory tributary to Cincinnati's industries. The territory within a radius of 300 miles was originally selected as a field, although the area actually covered has been largely governed by the nature of the materials surveyed. Funds were provided by a group of Cincinnati business men and amount to a total sum of $50,000.

The staff of the survey consists of selected members of the faculty of the University of Cincinnati and a few assistants who are advanced co-operative students in the College of Engineering.

The object of a survey of this kind is first, to benefit industries already established in the city by revealing the nearest available and best supplies of raw materials, and second, to indicate other industries that may be profitably established. To further the latter purpose a survey of markets is also to be undertaken.

One of the two leading industries in Cincinnati is the manufacture of machinery, principally machine tools. In the latter industry it leads the cities of the world. Castings of all kinds are required by these machinery manufacturers and as a result, the foundry became one of the important factors to be considered by the survey. Among the foundry cities of this country Cincinnati ranks eighth with 65 active foundries in the city proper; this number is increased to 93 when the outlying districts are included.

Consequently, the raw materials of the foundry were among the first to be considered. This report deals entirely with the progress of the work on molding sand.

*University of Cincinnati.

Territory Covered

It was originally intended to cover the entire 300-mile territory. However, after some preliminary work we discovered that a large portion of this field, viz: the states Kentucky, Tennessee, Illinois and Michigan, had been thoroughly covered by the Joint

MAP SHOWING TERRITORY COVERED BY THE CINCINNATI RESOURCE SURVEY

Committee on Molding Sand Research of the American Foundrymen's Association. We also learned that due to circumstances beyond its control, this committee had been unable to carry its work into Ohio, Indiana and West Virginia, the states in which we are most interested.

Ohio heads the list of states in the production of molding

sands, and as a foundry state it ranks second only to Pennsylvania, with a total of 656 foundries. Indiana ranks ninth as a foundry state with 245 foundries, and the production of molding sand is well developed as an industry in several localities. West Virginia is an unknown quantity as far as sand production is concerned and has 49 foundries.

Collection of Samples

The method of collecting samples from both producers and foundries has been principally through correspondence. Form letters were sent out to every sand producer in the district, 96 in all. The letters asked the exact location of pits, monthly production, railroad facilities, whether sand was milled, and for what type of work each sand was being used. A. F. A. analyses or 20-pound samples of each sand were also requested. Attached to these letters were full A. F. A. sampling directions. Sixty per cent of the producers replied and promised to send samples. The samples, however, have been rather slow in coming in.

To check back on the producers and principally to learn for what kinds of work the sands in our territory were being used successfully, form letters were sent to 200 foundries of various types, the leading ones in the district. These letters requested information as to the sands which each foundry had found most successful for its work, location of producer furnishing these sands, and either A. F. A. constants or 20-pound samples of both new sands and heap sands. Through these letters we also expect to determine the quantity of foreign[1] sand being used. The results of these letters were discouraging. Twenty-seven, or only 13 per cent of the total foundries outside Cincinnati replied.

All information received from foundries is considered as strictly confidential. Also, the names of the foundries giving such information will not appear in the final report. No results on any individual heap sand will appear, unless specially authorized by the concern where the sand was obtained.

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[1]Throughout this discussion the term "foreign" is applied to all sands outside the 300 mile zone of the survey. The term "local" applies to sands within this zone. The term "district" is applied to territory within the zone of the survey.

The reasons for requesting data on heap sands will be taken up later.

Recently the state geologist of West Virginia has agreed to do field work in that state and to send the samples which he collects to our laboratory. Conversation is now under way with the Indiana state geologist, and we hope within the near future to reach a similar agreement.

Kentucky has also sent in fifteen sands which when tested will complete the work which Dr. Ries began in this state.

In Ohio we have already tested samples of all important produced grades. We have not sufficient funds for field work, and without the co-operation of the State Survey, which we have been unable to obtain, it will be impossible to locate and classify the deposits which are now being worked. Thus, we shall have to leave the work in our most important state unfinished, unless we can find a way to finance the field work.

It would seem that field work of this kind might properly be taken up by the State Geologic Survey. Up to this time, however, no work on molding sands has been attempted by that survey.

Test Methods

All sands were tested according to standard A. F. A. methods for permeability, cohesiveness and fineness. Tests for base permeability as outlined* by H. W. Dietert of the U. S. Radiator Company will also be made on all sands.

Tests for life, dye-adsorption, and refractoriness have been deferred, as there was some question as to their value under present methods. We hope that after the discussion of these tests at this meeting we may take some definite action concerning them. I might also add that an investigation of the adsorption of dyes by various types of sands and clays is now under way at the University of Cincinnati.

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*Dietert, H. W., Commercial Application of Molding Sand Testing. Trans. A. F. A., Vol. 32, part 2, p. 32 (1925).

Sands Tested

Up to the present time we have data on 105 sands. The data on 47 produced sands of Ohio are submitted to the Association with this report. These sands are typical examples from the districts indicated on the accompanying map, Fig. 1, and represent a selection from which sands for any work may be chosen.

In addition to the new sands we have complete data on 35 heap sands from foundries of various types. These heaps were all made up from either a single local sand or mixture of local sands. We also have tested 6 foreign sands.

At the present time there is in our laboratory an accumulation of samples amounting to ten heap sands, and twenty-five new sands, not including the samples expected from the Indiana and West Virginia State Surveys and received from the Kentucky Survey.

During our investigation we have found pure local sands and mixtures of local sands which can be and are being used very successfully as substitutes for the more expensive eastern grades. In order that this work may be as practical as possible, we have obtained the co-operation of several local foundries, who have agreed to make trial pourings with molds made from sand mixtures which we recommend.

Uses of Sands

For our purpose it will be necessary to classify the sands according to the type of work for which they are best suited. This is accomplished through the recommendation of the producer, and the actual success of sands or mixtures of sands as reported by the foundries.

The analyses of the heap sands are intended to fulfill a twofold purpose. First, we are anxious to know how certain local sands actually behave in the heap, and we also intend to learn whether certain limits of cohesiveness, permeability, and grain size can be fixed for different classes of work.

In other words, sand from foundries doing similar work are compared with respect to their A. F. A. tests. From the com-

parison of many heaps we finally hope to see whether it is feasible to fix limits for different classes of work.

Of course, we realize that in a jobbing shop, for instance, castings of practically the same weight and measurements, but differently shaped and cored, require heaps with slightly different characteristics. We also realize that the different methods of foundry practice such as use or absence of the vent wire, will make it still more difficult to get coherent results from an investigation of this kind. Nevertheless, there must be certain limits for sands used for castings which lie within a certain range of weight and size. We are keeping up our interest in this phase of our work for the sole purpose of discovering whether standardization along the lines proposed is possible. In other words, there must be a "best" sand for each class of work and we are trying to find, as closely as possible, this "best" sand for the foundrymen of our district, at the lowest possible cost.

We are well aware of the fact that it will be a good many years before standard sand specifications for various classes of work will be adopted. We are simply making an attempt to hasten the final solution of this extremely important problem.

Grading of Sands

We have not decided upon a definite method of classifying our sands according to their screen analyses, and are anxiously awaiting the decision of the sub-committee on grading of the American Foundrymen's Association in regard to a standard method. The knowledge gained from the reports of the foundries, concerning the actual behavior of the sands in the heap, will be used as a basis for more practical grading.

Other Work

The thesis time of students working for engineer's degrees at the University has been placed at the disposal of the Resource Survey.

Thus any problems which arise in connection with survey work may be turned over to these students. Several molding sand problems have already been suggested by us for this work.

Acknowledgment

In conclusion we wish to acknowledge the co-operation of the producers and foundries who have given us valuable assistance in this work.

To Mr. W. D. Johnston, Jr., formerly of the Resource Survey, is due the credit of the suggestion, planning, and preliminary work of this investigation. Dr. H. Ries of Cornell University suggested test methods to be used and has given us other valuable advice; a co-operative understanding exists between him and our Survey.

DISCUSSION

P. W. CRANE: If anyone present can bring to our attention any data which would be helpful to us, we should appreciate such a favor, or if there are any suggestions regarding any phase of our work, we shall be delighted to hear them. We realize that we have entered into this work from a more or less laboratory or scientific standpoint. For this reason we are particularly glad to have experienced foundrymen raise questions which may help to place our work on a more practical basis. We are also anxious to learn the location of any producing districts which do not appear on our present map.

R. A. BULL: Can Mr. Crane let us have the reasons advanced by the state geologist for not taking up this work?

P. W. CRANE: We have approached the state geologist on several occasions with regard to this matter. His answer has been a lack of funds available for work of this kind.

APPENDIX

Molding Sand Work at The University of Cincinnati Survey and Test Data of Ohio Molding Sands

Ohio

ASHTABULA COUNTY

Lab No.: 14.
Location: Conneaut.
Producer: Buckeye Sand Co., Conneaut.
Grade: Brass, Light Grey Iron, Light Malleable.

Lab. No.: 17.
Location: Conneaut.
Producer: Buckeye Sand Co., Conneaut.
Grade: Brass, Light Grey Iron, Light Malleable.

BUTLER COUNTY

Lab. No.: G-7.
Location: Overbeck, Ohio.
Producer: Hamilton Molding Sand Co., Hamilton, O.
Grade: Heavy Grey Iron.

ERIE COUNTY

Lab. No.: 5-J.
Location: Smith's Siding.
Producer: Ross Cheny.
Grade: Opener for Heaps.

Lab. No.: G-4.
Location: Avery.
Producer: Keener Sand & Clay Co., Columbus, O.
Grade: Brass and Light Malleable.

Lab. No. 29.
Location: Avery.
Producer: J. K. Boehm, Huron, Ohio.
Grade: Light Iron and Brass.

Lab. No. 27.
Location: Ceylon.
Producer: J. K. Boehm, Huron, Ohio.
Grade: Brass.

Lab. No.: 28.
Location: Milan.
Producer: J. K. Boehm, Huron, Ohio.
Grade: Brass.

Lab. No.: 1.
Location: Milan.
Producer: A. Arnold, Milan, Ohio.
Grade: Light Grey Iron.

Lab. No.: 39.
Location: Shinrock.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Light and Medium Brass, Light Grey Iron and Malleable Stove Plate.

Lab. No.: 38.
Location: Shinrock.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Light Grey Iron and Malleable, Light and Medium Brass, Stove Plate.

Lab. No.: 37.
Location: Shinrock.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Light Grey Iron and Malleable, Automobile Castings.

GALLIA COUNTY

Lab. No.: 41.
Location: Gallipolis.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Heavy Grey Iron and Malleable, Pipe Work.

Lab. No.: 54.
Location: Gallipolis.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Grey Iron.

Lab. No.: 53.
Location: Gallipolis.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Brass and Aluminum.

Lab. No.: 82.
Location: Gallipolis.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Heavy Grey Iron.

Lab. No.: 56.
Location: Mills.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Used for bond renewal and blending.

Lab. No.: 57.
Location: Mills.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Grey Iron.

Lab. No.: 50.
Location: Bidwell.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Heavy Castings.

Lab. No.: 49.
Location: Bidwell.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Heavy Grey Iron.

Lab. No.: 48.
Location: Bidwell.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Grey Iron and Malleable Castings.

Lab. No.: 83.
Location: Bidwell.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Medium Heavy Grey Iron.

Lab. No.: 51.
Location: Cheshire.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Light Grey Iron and Brass.

Lab. No.: 52.
Location: Cheshire.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Very Light Grey Iron and Light Brass.

Lab. No.: G-2.
Location: Kerr's Station.
Producer: Keener Sand & Clay Co., Columbus, O.
Grade: Medium to Heavy Grey Iron.

HAMILTON COUNTY

Lab. No.: 19.
Location: Saylor Park Station.
Producer: Delhi Sand Bank Co.
Grade: Heavy Castings.

Lab. No.: 3-J.
Location: Delhi, Ohio.
Producer: S. C. Grimes, Cleves, Ohio.
Grade: Heavy Grey Iron.

Lab. No.: 1-J.
Location: Delhi, Ohio.
Producer: Newport Sand Bank Co., Newport, Ky.
Grade: Brass and Light Iron.

HURON COUNTY

Lab. No.: 4-J.
Location: Near Norwalk.
Producer: H. J. Mason, Norwalk, Ohio.
Grade: Opener for heaps.

JACKSON COUNTY

Lab. No.: 21.
Location: Jackson.
Producer: Jackson Sand Mining Co.
Grade: Core Sand.

MEIGS COUNTY

Lab. No.: 55.
Location: Middleport.
Producer: Hercules Sand Co., Gallipolis, Ohio.
Grade: Light Malleable, Bench Work.

PERRY COUNTY

Lab. No.: 43.
Location: New Lexington.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Car Wheels, Heavy Machinery, Medium Heavy Grey Iron.

Lab. No.: 42.
Location: New Lexington.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Hot Water Boilers.

Lab. No.: 44.
Location: New Lexington.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Hot Water Boilers.

Lab. No.: 20.
Location: New Lexington.
Producer: Ayers Mineral Co., Zanesville, Ohio.
Grade: Medium Heavy Grey Iron.

Lab. No.: G-1.
Location: New Lexington.
Producer: Jones Sand Co., Ontario Bldg., Columbus, Ohio.
Grade: Heavy Grey Iron.

Lab. No.: G-5.
Location: New Lexington.
Producer: Jones Sand Co., Columbus, Ohio.
Grade: Heavy Malleable Castings.

Lab. No.: G-6.
Location: New Lexington.
Producer: Jones Sand Co., Columbus, Ohio.
Grade: Automobile Cylinder Castings.

STARK COUNTY

Lab. No.: 47.
Location: Canal Fulton.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Light and Medium Brass, Light Grey Iron.

SUMMIT COUNTY

Lab. No.: 40.
Location: Botzum.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Light and Medium Grey Iron and Malleable; Heavy Brass.

TRUMBULL COUNTY

Lab. No.: 1-A.
Location: Phalanx.
Producer: Portage Silica Company, Youngstown, Ohio.
Grade: Steel Sand.

TUSCARAWAS COUNTY

Lab. No.: 45.
Location: New Cumberland.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Medium Grey Iron, Radiator and Automobile Castings.

Lab. No.: 46.
Location: New Cumberland.
Producer: Superior Sand Co., Cleveland, Ohio.
Grade: Medium Grey Iron, Car Wheels, Hot Water Boilers.

WAYNE COUNTY

Lab. No.: G-7.
Location: Kauke.
Producer: Jones Sand Co., Columbus, Ohio.
Grade: Light Brass and Aluminum.

Lab. No.: G-8.
Location: Kauke.
Producer: Jones Sand Co., Columbus, Ohio.
Grade: Light Grey Iron and Brass.

Lab. No.: G-9.
Location: Kauke.
Producer: Jones Sand Co., Columbus, Ohio.
Grade: Light Grey Iron.

Results of Tests on Ohio Molding Sands

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay	Total			
14	Ashtabula Co. Conneaut	Brass, light iron and Malleable	.....	.....	1.0	1.3	1.8	6.8	42.3	9.7	2.8	19.3	15.0	100.0	4.3 7.6 10.3	215 238 224	8.0 17.3 16.5
17	Ashtabula Co. Conneaut	Brass, light Iron and Malleable	.....	.....	.2	.8	2.2	8.2	13.2	6.6	3.4	46.2	19.2	100.0	5.0 7.2 8.6 9.5	195 243 270 248	2.32 3.65 4.70 5.90
G-7	Butler Co. Overpeck	Heavy Gray Iron	2.12	1.64	3.76	7.48	45.0	10.16	2.08	1.62	.88	3.60	21.66	100.0	6.9 8.6 10.6 12.3 14.6	350 360 364 369 352	142 166 127 83 32
5-J	Erie Co. Smith's Siding	Opener for Heaps	.....	.....	.....	2.32	10.62	37.74	37.56	3.24	.64	2.18	5.70	100.0	4.2 6.2 7.5 10.1	105 107 104 101	67 64 61 53
G-4	Erie Co. Avery	Brass and Light Malleable	.....	.47	.44	.61	3.36	4.15	3.48	19.76	40.24	18.27	9.22	100.0	6.0 7.0	 160	17.0 .....
29	Erie Co. Avery	Light Iron and Brass	.1	.3	.4	5.9	14.2	11.7	36.7	13.5	2.6	6.1	8.5	100.0	4.1 5.9 6.6 8.2	148 137 138 141	39 40 45 37
27	Erie Co. Ceylon	Brass	.....	.....	.....	.2	1.6	11.1	49.2	13.3	5.0	9.9	9.7	100.0	5.0 5.9 6.9 8.0	137 144 142 161	31 34 36 35
28	Erie Co. Milan	Brass	.3	.9	.7	3.0	17.5	36.3	24.0	2.9	.4	4.8	9.2	100.0	4.1 5.6 7.2 8.0	135 139 138 133	56 64 70 75
1	Erie Co. Milan	Light Grey Iron	.....	.86	1.30	6.64	15.62	26.6	23.29	3.50	1.20	9.00	12.00	100.0	4.0 6.2 8.0	190 192 133	41 55 60
39	Erie Co. Shinrock	Light and Medium Brass, Light Iron and Malleable Stove Plate	.....	.16	.16	.90	1.20	1.78	19.50	25.12	13.80	25.38	12.00	100.0	4.7 5.4 8.1 8.3 9.9	161 170 246 225 198	18 15 11 10 9
38	Erie Co. Shinrock	Light and Medium Brass, Light Iron and Malleable Stove Plate	.....	.....	.6	.9	1.12	1.90	14.4	22.6	13.6	33.4	11.48	100.0	4.3 6.1 7.7 9.0	147 213 175 145	9 11 12 16
37	Erie Co. Shinrock	Light Iron and Malleable Auto Castings	.....	.....	.....	1.70	4.90	7.20	29.50	24.2	8.3	17.4	6.8	100.00	5.2 6.9 8.5 9.1	142 158 139 136	26 27 42 20
41	Gallia Co. Gallipolis	Heavy Iron and Malleable Pipe Work	.2	.88	1.46	18.4	16.44	9.18	4.58	1.74	.70	6.40	40.02	100.0	6.0 7.8 8.4 10.3	193 308 370 327	63 101 81 78
54	Gallia Co. Gallipolis	Medium Iron	.....	.....	.....	.42	13.96	30.28	20.92	5.42	1.46	8.82	18.72	100.0	5.7 6.5 8.3 10.2	241 251 254 215	47 43 37 31
53	Gallia Co. Gallipolis	Brass and Aluminum	.....	.....	.....	.04	.20	.32	.66	1.20	1.16	81.98	14.44	100.0	4.7 5.8 7.65 9.4 11.9	141 153 160 173 167	2.4 2.7 2.8 2.7 2.6
82	Gallia Co. Gallipolis	Medium Heavy Iron	.....	.....	.02	.65	16.79	25.20	17.04	7.46	3.81	8.49	20.54	100.0	6.4 7.1 8.0 8.7	300 260 278 251	46 46 51 45

{All samples having Label Nos. with prefix G were tested in laboratory of Ohio Brass Co., Mansfield, Ohio, by A. A. Grubb.

Results of Tests on Ohio Molding Sands

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay	Total			
56	Gallia Co. Mills	For Bond Renewals and Blending	.....	.....	.42	1.68	10.00	19.86	18.58	4.02	1.22	10.30	33.92	100.0	5.2 6.1 8.0 9.8 11.0	199 216 326 348 336	25 27 30 35 27
57	Gallia Co. Mills	Medium Iron	.....	.....	.....	.72	17.32	28.62	17.29	3.36	.80	4.80	27.14	100.0	4.8 6.0 8.0 9.6 11.6	222 276 319 320 272	39 44 51 40 21
50	Gallia Co. Bidwell	Heavy Iron	.....	.....	.....	13.18	47.16	14.98	4.34	.92	.28	1.58	17.56	100.0	5.0 6.1 7.5 9.7	251 288 257 209	137 144 117 83
49	Gallia Co. Bidwell	Medium Heavy Iron	.....	1.72	1.16	15.22	22.92	12.82	8.9	2.96	.88	6.04	27.38	100.0	5.7 6.6 8.5 10.1	228 264 290 292	54 55 57 51
48	Gallia Co. Bidwell	Medium Iron and Malleable	.....	.....	.....	.48	7.44	26.16	28.98	7.74	2.68	10.2	16.32	100.0	5.1 5.9 8.0 9.6	164 168 165 144	41 46 41 39
83	Gallia Co. Bidwell	Medium Heavy Iron	.....	.....	.25	2.21	14.45	16.10	11.73	6.88	4.69	14.91	28.78	100.0	6.4 7.4 8.2 9.1	287 347 327 309	30 41 33 32
51	Gallia Co. Cheshire	Light Iron and Brass	.....	.....	.....	.14	.26	2.98	16.66	14.16	8.50	45.86	11.44	100.0	4.9 5.8 7.6 9.0 10.7	116 130 145 151 146	7.0 8.3 8.8 10.0 9.4
52	Gallia Co. Cheshire	Very Light Iron and Light Brass	.....	.....	.....	.12	.26	1.18	6.78	8.32	5.50	67.20	10.64	100.0	4.6 5.5 7.2 9.5 11.7	115 137 154 164 163	5.0 5.6 5.8 6.0 5.7
G-2	Gallia Co. Kerrs Station	Medium to Heavy Iron	.....	.17	.24	3.18	34.85	13.00	6.98	3.68	3.37	7.82	27.31	100.0	4.4 6.8 8.9 11.0 13.1	286 333 315 355 340	45 67 103 62 32
19	Hamilton Co. Sayler Park Sta.	Heavy Iron	3.0	2.4	2.0	12.6	17.0	12.0	10.8	5.0	2.4	16.4	16.4	100.0	6.4 8.1 9.8 10.2	228 340 454 429	16 35 36 33
3-J	Hamilton Co. Delhi	Heavy Iron	.....	.84	.88	14.56	23.12	13.70	7.30	2.36	.88	6.36	30.0	100.0	9.5 11.6 18.5	334 364 354	104 107 97
1-J	Hamilton Co. Delhi	Brass and Light Iron	.....	.....	.....	.08	.16	.38	1.60	2.70	2.68	63.16	29.24	100.0	5.5 7.2 8.5 11.8 12.9	..... 242 245 224 222	2.5 3.2 4.0 5.2 4.7
4-J	Huron Co. Norwalk	Opener for Heaps	.....	1.54	1.04	10.12	25.54	22.04	14.82	5.04	1.56	8.30	10.00	100.0	4.2 6.0 7.5 10.0	114 121 104 103	34 58 79 68
21	Jackson Co. Jackson	Cores	.....	.....	.6	4.6	26.8	38.0	15.6	3.4	1.0	4.2	5.8	100.0	3.0 4.8 6.6 7.8	112 113 115 118	98 122 120 99
55	Meigs Co. Middleport	Light Malleable Bench Work	.....	.....	.....	.08	1.16	6.54	14.42	11.30	5.66	48.66	12.18	100.0	4.6 5.4 7.2 9.5 11.4	126 137 156 161 159	5.4 5.7 6.3 7.6 7.7

Results of Tests on Ohio Molding Sands

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay	Total			
43	Perry Co. New Lexington..	Car Wheels, Heavy Machine, Medium Heavy Iron.....	.....	1.5	.34	9.1	24.2	11.28	5.08	1.94	.94	14.54	31.08	100.0	6.8 7.7 10.0 11.0	175 204 254 334	22 36 37 20
42	Perry Co. New Lexington..	Hot Water Boilers	.60	1.10	.60	8.90	25.32	10.28	4.72	1.80	.84	15.54	30.30	100.0	7.2 7.8 9.0 9.9	168 188 195 222	22 45 45 25
44	Perry Co. New Lexington..	Medium Heavy Iron.....	.....	2.4	.9	17.0	28.96	10.26	4.2	1.7	.64	11.14	22.8	100.0	5.6 6.8 8.4 10.5	153 189 225 228	28 31 41 39
20	Perry Co. New Lexington..	Medium Heavy Iron.....	.....	1.4	2.6	29.8	12.7	5.3	4.1	1.8	.9	19.0	22.4	100.0	5.5 8.0 9.4 10.0	204 265 300 294	24 42 50 32
G-1	Perry Co. New Lexington..	Heavy Iron.....	.....	.....	3.70	29.83	15.00	5.70	1.62	2.06	1.54	10.83	29.72	100.0	6.7 8.8 10.3 12.1 13.4	181 238 290 315 262	121 144 145 79 9
G-5	Perry Co. New Lexington..	Heavy Malleable.	.....	.....	3.30	30.33	22.74	6.07	.94	2.92	1.36	9.86	22.48	100.0	5.0 6.4 7.5 9.6 11.2 12.9	115 123 183 232 230 225	89 91 126 136 123 37
G-6	Perry Co. New Lexington..	Auto Cyl.....	.....	.....	2.70	32.35	21.30	16.88	3.78	2.18	2.36	5.69	12.76	100.0	4.5 6.4 8.1 9.7 11.0	122 130 125 104 95	36 102 125 131 126
47	Stark Co. Canal Fulton....	Light and Medium Brass Light Iron	.....	.....	.....	.08	.22	.62	2.0	5.0	4.56	76.4	11.12	100.0	5.8 6.8 8.2 9.2 10.6	150 155 .... 158 171	4.6 ..... 4.7 4.9 4.5
40	Sumit Co. Botsum.....	Heavy Brass, Light and Medium Iron.....	.....	.....	.....	2.0	19.0	23.7	17.1	5.7	1.8	16.9	13.8	100.0	5.3 6.6 7.1 7.9 9.1	175 201 180 174 152	30 31 33 34 41
1-A	Trumbull Co. Phalanx.....	Steel.....	.....	12.0	16.4	57.0	9.5	1.9	.2	.....	.....	.2	2.7	100.0	2.4 3.8 5.8	53 57 60	984 805 729
45	Tuscarawas Co. New Cumberland.....	Medium Iron, Radiator and Auto Castings...	.....	.....	.....	2.84	22.32	18.64	14.	5.06	1.8	17.92	17.42	100.0	5.5 6.6 7.8 8.2 9.9 10.6	165 177 227 .... 190	23 24 ..... 26 35 29
46	Tuscarawas Co. New Cumberland.....	Medium Iron, Car Wheels, Water Boilers.....	.....	.....	.....	2.14	29.46	29.16	13.36	3.60	1.12	10.2	10.96	100.0	4.9 6.0 7.6 9.4	139 149 134 116	52 65 57 53
G-7	Wayne Co. Kauke.....	Light Brass and Aluminum.....	.....	.....	.....	.....	.02	.25	.60	5.52	7.66	76.63	9.32	100.0	3.5 6.5 8.6 10.4 13.7	100 128 145 140 137	5.8 7.7 9.0 8.2 7.2
G-8	Wayne Co. Kauke	Light Iron and Brass.....	.....	.01	.08	.13	.20	.49	.80	9.18	16.20	64.69	8.22	100.0	4.4 6.6 8.9 11.1	116 136 144 142	9.2 10.7 12.4 10.5
G-9	Wayne Co. Kauke.....	Light Iron.....	.....	.....	.....	.....	.02	1.38	2.59	31.82	27.84	32.83	3.52	100.0	4 6.2 9.2 12.1	97 119 129 107	29 30 28 27

Report of Chairman of Joint Committee on Molding Sand Research

To the members of the American Foundrymen's Association:

During the past year the Joint Committee on Molding Sand Research has made considerable advance along some new lines, as well as carrying on the investigations begun in previous years. This work has been done by the sub-committees, which have made valuable progress, each in its different field.

During the year F. L. Wolf, chairman of the Sub-committee on Conservation and Reclamation, found it necessary to relinquish active work, and consequently his resignation was accepted by the Executive Committee of the Joint Committee on Molding Sand Research. In his place R. F. Harrington was elected, who at once took up the work and with his committee has undertaken the study of the methods used in different foundries for reclaiming and conserving molding sand.

The Sub-committee on Tests has been studying new methods of testing molding sand, particularly a method for determining the softening temperature of sands when in contact with molten iron.

The Sub-committee on Geological Surveys has continued collecting and testing molding sands, obtained through the various state geological surveys. It is expected this work will be continued until all states have been canvassed and tests made to determine the value of their sands.

A new committee, known as the Sub-committee on Grading, has been formed to consider and study the methods now in use and to suggest a uniform system of grading molding sands. This sub-committee, under the able leadership of A. A. Grubb, has given valuable time to the subject and is making a careful survey of the methods of grading molding sands used in the United States.

The chairman of these committees will present reports, giving detailed results of their work.

The personnel of the joint committee remains about the same as last reported. One member has died, one resigned, and five new members have been elected by the Executive Committee. The total membership of the Joint Committee on Molding Sand Research is now 64 persons.

As in the past, the members have given their services without compensation. In many instances the expenses of work done by members, have been met by the companies with which they are connected.

The Joint Committee on Molding Sand Research depends upon contributions from the various foundry interests to defray expenses connected with the work. Expenses such as clerical assistance, stationery, traveling, and assistance in testing, necessarily have to be met from funds of the committee.

The introduction of tests recommended by the joint committee has saved money for many foundries by improving their molding sand and the quality of castings produced. It has been suggested that the foundries which have actually profited from the results of the research should contribute part of the profit to the work of the Joint Committee on Molding Sand Research. Some foundries have made such contributions. If all these foundries paid a very small percentage of the value which they received, it would result in great assistance in the continuation of the research work.

Respectfully submitted,

WALTER M. SAUNDERS, *Chairman*,
Joint Committee on Molding Sand Research.

October 7, 1925.

Report of Sub-Committee on Grading of Foundry Sands

To the Members of the American Foundrymen's Association:

The appointment of a Sub-Committee on Grading was authorized by the Executive Committee of the Joint Committee on Molding Sand Research at its meeting in Milwaukee in October, 1924. The membership was designated shortly afterward by the chairman of the Executive Committee and active work on the problem was started February 21st of this year by a meeting held at Ithaca, N. Y.

The authorization and appointment of this sub-committee was the result of a growing sentiment among sand producers and foundrymen that a uniform method of grading foundry sands would be of advantage to all concerned. While nearly every producer has for years attempted to grade his sands, the systems employed have differed radically and as a result there has been much confusion when foundrymen attempted to discuss grades among themselves or with the various producers. It was felt that the value of any system of grading depended, not on how well it could be applied to the sands of one producer or of one section, but rather on how generally it could be applied and understood. It was believed that the producers would be reluctant to subscribe to a common system of grading, but this belief has not been justified; on the contrary, there has actually been evidence of impatience on the part of the producers to have a practical system of grading recommended to them.

The nature of the problem, however, does not permit haste in its solution. Sand is such a variable material, such a variety of methods are employed in mining and handling it and such a wide diversity of opinion exists regarding sand values that the process of developing a satisfactory system of grading must necessarily be a slow one. It is believed that the delay of a couple years or even more is preferable to the adoption of an arbitrary system that would not only excite the criticism of future investi-

gators but might actually necessitate the re-grading of thousands of samples of sand.

At the February meeting of the sub-committee, the following general ideas of the problem and scheme of procedure were presented.

The value or adaptability of any particular sand for a given purpose depends on several properties or characteristics. Among these we might mention grain size or texture, clay content, colloid content or dye adsorption value, chemical analysis, permeability, bond, durability, refractoriness, etc. No one of these properties alone can define the value of a sand. Nor do we know how many such factors there are. Complete grading would involve every such characteristic, and would involve as many sets of grading numbers, letters or other symbols.

It was agreed that, of all these properties, the fineness or texture of grain should be the subject of our first efforts at grading. This is in accord with general practice, for most of the producers are assigning numbers from 00 up to 6 or even 8 to their sands, the lower numbers representing the finer and the higher numbers the coarser sands. It was further agreed that the fineness or texture grading should be based on the grain alone after washing out the clay substance according to the standard A. F. A. fineness method. It should be noted that any series of grade numbers representing the various textures of grain carries no information regarding the clay content or other unrelated properties of the sand. It is intended to study these properties further before determining which of them should serve as bases for further classification.

The next question facing the sub-committee was this: How can we obtain from the screen data of the sand grain an index figure which will most nearly represent the texture of that grain? Textures and fineness are rather vague terms. Do they mean the average grain size based on number or based on weight, the average mesh, the predominant grain size, or what? A complete screen analysis made according to the standard A. F. A. method may involve as many as ten variables—each screen affords a variable. Some method must be found to represent all these variables, each of which is a factor in determining texture of

grain, by a single index number which is a mean or average value. Furthermore this index number should be related as closely as possible to those working properties of sand which are determined in part at least by texture of grain.

Several methods were proposed for arriving at this index figure. All have their merits so each will be outlined briefly.

Graphic Methods

Two types of graphic methods were proposed. The first plots screen mesh numbers or log of sieve openings[1] as abscissae against percentages on each screen. Tolerance zones are established and grade numbers are assigned to each zone. The other plots index numbers representing the mesh numbers as abscissae against cumulated percentages of grain. The index number, called median index, at which the cumulative curve cuts the 50 per cent ordinate, is taken as the grade number of the grain.

Calculative Methods

Two methods for calculating index figures were proposed. A coarseness factor may be derived by dividing each fraction of grain by the mesh of the screen on which it was caught and adding the quotients. An average fineness factor may be calculated by multiplying each fraction of grain by the mesh number of the screen through which it passed, adding the products and dividing by the sum of the fractions.

The following points of advantage or disadvantage for each method were mentioned by members of the sub-committee and are given here briefly without argument.

The graphic methods picture the complete grain distribution. Grade numbers based on tolerance zones, however, cannot carry with them this complete information. Question may exist as to which grade zone the distribution curve of a given sand belongs. The median index avoids possibility of such question by yielding a definite value.

The calculative methods yield definite values for all sands. The coarseness factor emphasizes or weights the coarse material in a sample more than the fine material. The fineness factor em-

[1]Nevin: Notes on Grading of Sand, Trans. A. F. A., Vol. XXXII, Part 2, 1925.

phasizes or weights the fine material. The median index weights neither. Fineness factors are very roughly proportional to the surface areas of sands.

The proposed methods were tried out on a large number of sands, the fineness data on which were available and arguments pro and con were exchanged. In a meeting of the sub-committee at Cleveland, September 17th, the above mentioned points were discussed further with particular reference to their relation to the working properties of sands. The members present then went on record unanimously as favoring a special fineness factor which will be known as the A. F. A. fineness factor, to be used as a basis for grading foundry sands as to texture of grain; this factor to be calculated as described above under *Calculative Methods* except that instead of the series of standard screen numbers which are used as multipliers, a special series of numbers more nearly proportional to the surface area of the grain increments passing each screen, is to be used. This results in a fineness factor which is more nearly proportional to the surface area of a sand than is the usual factor and is closely related to the working properties, particularly permeability and texture of mold surface. These A. F. A. fineness factors range from low numbers for coarse grained sands to numbers in the neighborhood of 300 for very fine sands. It is proposed to study their application to a large number of representative foundry sands and then, if it appears practical, to establish zone limits for each grade number so that all A. F. A. factors between certain limits will define No. 1 sands, all between certain other limits, No. 2 sands, etc. As mentioned above, these grade numbers will be descriptive of the grain texture only and will have no reference to clay content, permeability, bond, refractoriness, etc., except in so far as any of these properties may be influenced by, or related to, texture of grain.

In conclusion the sub-committee wishes to express appreciation of the active interest that is being shown in the grading problem. We trust that this interest will continue to the final adoption of a satisfactory system of grading.

Respectfully submitted,

A. A. GRUBB, *Chairman*
Sub-committee on Grading.

Report of Sub-Committee on Conservation and Reclamation

To the members of the American Foundrymen's Association:

Since the last report of the sub-committee on conversation and reclamation presented by the chairman, F. L. Wolf, there have been many papers presented by various committee members and others covering the subject of molding sand conservation and reclamation.

These are a matter of record in the American Foundrymen's Association transactions, Volume 32, Part 2, of the Milwaukee convention in 1924. These reports were in fact records of tests which covered the various lines of investigation already under way in the various plants, or instigated by the committee through its various members. Since the Milwaukee convention of 1924 many conservation and reclamation tests have been inaugurated by the committee or its members.

In April, 1925 the former chairman, F. L. Wolf, because of the pressure of other work found it necessary to resign, the work since that time having been taken over by the present chairman. It is to be regretted that Mr. Wolf, who has been an able chairman and actively engaged in conservation and reclamation work within his own plant, found it necessary to resign. It is to be hoped, however, that the work of the committee can be extended and become effective through the greater interest created by the increased number of plants engaged in actual conservation work. Your chairman has endeavored to keep in close touch with developments throughout the country on the question of conservation and reclamation.

A meeting was held in May of this year with the general chairman, Walter Saunders, and Dr. Moore of the Dorr Co., at the offices of the Dorr Co., New York City. At this time the previous test inaugurated by Mr. Wolf was discussed, and further tests inaugurated in an endeavor to determine the desirability of attempting further tests upon the separation of the various grain constituents in foundry waste sands. It is to be regretted that

further progress can not be reported on the outcome of this test. It can be said, however, that the test to date would seem to indicate definite possibilities for the treatment of sands for the purpose of separating the various grain constituents.

Bearing upon the general subject of sand conservation and reclamation, we have many papers to be presented at the convention this year. A test performed upon spent fire clay removed from foundry waste sands and also upon a clay removed from a new Millville gravel for the purpose of increasing the colloidal value through proper milling action has been completed.

The so-called colloid mill employed in this test developed an increase of 157 per cent tensile strength upon the new clay and 27 per cent in the case of clay from the spent molding sand. It is hoped that arrangements can be made by the committee for the development of tests along this line on a practical shop basis. It is felt that in view of these preliminary tests this phase of sand treatment making possible increased effectiveness of bonding material through greater development of the colloidal matter present should form an important part of our future investigative work.

After having given considerable thought and study to the general situation of sand conservation and reclamation, it is the belief of the committee that molding sand conservation should occupy the first place in our consideration of work for the next year. It seems to your chairman that this is the one logical procedure. That is to say, conserve or reduce our molding sand purchases—first, by means of selecting that material best suited for the work; second, if nature fails to give us the best, improve it by such means as we can bring to bear which will accomplish the results; third, make each pound of new sand or new material bound the maximum amount of old material by providing the most efficient means of mixing and preparing the sand. It would seem that with this phase of the problem properly under way, then the problem of reclamation should properly be attacked.

For some time in the grey iron or malleable field there have been many attempts made to make use of molding sand substitutes in the way of various clays or hightly bonded sands. The A. F. A. transactions show definite records of this substitution

upon an experimental or semi-experimental basis in the reports of various investigators in the grey iron field over the last eight or ten years. It has not been however until within the last year or two that any general progress has been made on a practical shop basis, especially where only one or two per cent additions of the bonding material have been employed and where operation has continued for several months or a year with no unusual difficulties.

Many favorable reports have come to the writer's attention from foundries actually employing these products on a production basis. This report indicates that over periods of time varying from three months to a year practically no new sand has been employed in many instances, while in others a marked reduction in new sand has invariably taken place. These reports are of such a character that they can not properly be ignored, particularly as they come from plants whose operating men are entirely capable of presenting the true facts of the situation.

The introduction of such products as a substitute for molding sand has brought out the effectiveness of intensive mixing and it is difficult to show definitely that part attributable to the clay product and that part attributable to the intensive mixing.

The committee, therefore, commends for the serious consideration of the foundrymen both the question of the clay products, or other highly bonded material, and the more extended use of the muller or similar type of intensive mixing equipment.

Your committee desires to go on record as pointing out that with the American Foundrymen's Association methods of sand testing which are now available, that these molding sand substitutes or similar products should meet with far greater success than in the past.

It is the belief of the committee that had the earlier investigators the advantages of the carefully worked out A. F. A. tests for permeability, bond, etc., that today many plants would have been operating with molding sand substitutes with a consequent reduction in new material costs. In fact, it has been the observation of your chairman of the sub-committee on Molding Sand

Conservation and Reclamation that more is being accomplished along the lines of sand conservation than ever before directly through the application of the American Foundrymen's Association molding sand tests. These tests properly applied have allowed for the choice of that material best suited for the work involved, together with a minimum amount of new material necessary to accomplish the desired results.

Briefly, it is the desire of the committee to leave the following salient points before the association:

1. Conservation as the first step.
2. Proper selection of material as a means to that end.
3. Treatment of that material, if necessary, to develop its desirable properties.
4. Intensive mixing and preparation in order that each pound of new material may bond the maximum amount of old sand.
5. Application of American Foundrymen's Association tests as an aid to better molding sand control, conservation and reclamation.

It is to be hoped, that through the knowledge that is now available through the efforts of our various committees that foundrymen will soon begin to appreciate the possibilities of molding sand control, conservation and reclamation. To many it may have appeared that progress has been slow. To these we can say that while progress seems to have been slow the foundations have been well prepared which should result in more rapidly reaching the goal of the desires of every foundry for quality castings at a minimum cost for new material with maximum percentage of good castings.

At this time the chairman wishes to express his appreciation to the various members of the committee for their interest and co-operation.

Respectfully submitted,

R. F. HARRINGTON, *Chairman,*
Sub. Committee on Conservation and Reclamation.

DISCUSSION

FRED E. HAND: Has the committee determined or formed any idea about the proper amount of new sand needed in proportion to tons of castings produced over a given length of time, that is what a well-handled foundry should use?

R. F. HARRINGTON: Answering the gentleman's questions, it seems to me that it is practically impossible to make a definite statement of fact on this point because each and every foundry has its different condition involved in their particular class of work; in other words, a ratio of a tenth of a pound of sand to a pound of castings would be eminently satisfactory in one class of work; one to one in another, and half a pound of sand to a pound of castings might be eminently satisfactory in another. When the various classes of foundries are studied then I think that it might be possible to answer your question. Now we really have not sufficient data to say to you that in general, steel foundry operation should show a result of half a ton of sand to a ton of castings, or what. No matter how much studied, it would be somewhat difficult because of the very great difference in the character of work in the steel group, the gray iron group, etc.

S. R. ROBINSON: I would like to ask what is meant by molding sand substitutes? Also, if the committee would investigate the air separation in steel molding sand?

R. F. HARRINGTON: By molding sand substitutes, we referred to any material that might substitute for the ordinary molding sand, and used in smaller quantities with a consequent reduction in the total amount of material used. In some parts of the country molding sand substitutes consist of clay products; in other parts of the country it may be a loam containing a very high percentage of clay, so I think my explanation covers your question. The latter part of your inquiry as to the use of air separation, also will be investigated by the sub-committee on steel sand.

E. W. SMITH: As to the committee report on sand conservation and sand reclamation—as I recollect it, about a year ago we devoted a great deal of time to sand reclamation. The question now is, has not that fallen by the wayside, except in a few very large foundries having cores in which the sand may be reclaimed? My inquiry refers to sand which has passed through the tumbling mill and other forms of wastage, which we formerly tried to reclaim. Do I understand your committee has about decided to leave that go and get to sand reclamation as the redeeming feature?

R. F. HARRINGTON: The thought I wish to convey and that the committee had in mind was this, that the greatest number of dollars can be saved in the average foundry by a consideration of the new material entering into the work, providing the very best material possible, providing

the most intensive means of mixing in order that sand may do the greatest amount of work. The committee has no intention whatever of dropping the possibility of tumbling mill recovery by any means, merely the committee went on record that it believed that its work should primarily deal with the question of conservation, believing that after all, that would net the greatest returns to the average foundryman, and that we could serve the average foundryman best by giving him the data that we have available on sand conservation. The committee does not intend by any means to eliminate entire consideration of tumbling mill waste and gangway waste.

E. W. SMITH: The committee has stated that in the coming year they were to devote their studies to steel sand. Did I understand that?

R. F. HARRINGTON: I think Mr. Smith possibly misunderstood the report. The report mentioned steel sand practically only in regard to the recovery of the various grain constituents. It was felt that any process of washing or of separation should be directed to the steel sand in preference to gray iron, malleable or non-ferrous sand. The work of the Committee on Conservation and Reclamation in general will cover both the gray iron and the steel field, non-ferrous and malleable.

E. W. SMITH: Having had pretty wide experience in past years in reference to trying to save sand that has been subjected to excess heat and excess sea coal, I doubt whether it is worth while to try to reclaim sand under those conditions. It would be far better to devote your time to a study of the sand you have and try to make it go as far as you can.

R. F. HARRINGTON: I am very glad indeed to have Mr. Smith make the statement he has made, for it conforms to the feeling of the committee. We all know that Mr. Smith is one of the pioneers in this question of sand conservation and a tremendous amount of credit is due Mr. Smith and his organization for the amount of work they have done and the things they have accomplished. Mr. Smith speaks as an authority.

R. A. BULL: I have not the slightest inclination to disagree so far as my own particular interests lie, with what the committee, through Mr. Harrington, has expressed and what Mr. Smith has expressed, but it just occurred to me while we have been talking that that does not represent the viewpoint of certain foundrymen who are rather remotely situated from satisfactory sources of supply. About three weeks ago I was talking with a man who operates a steel foundry in Portland, Oregon, who gets his sand from Ottawa, Illinois, and about three months ago I was talking with another man who operates a steel foundry in Los Angeles, who also gets his sand from Ottawa, Illinois. In each case it cost those men $12.00 a ton freight for their sand. Fellows situated like that are intensely interested, of course, in reclamation.

E. W. SMITH: In regard to Major Bull's remarks—I was out in Los Angeles a year ago and went through the sand question pretty thoroughly, and it is true they have to get all their sand by water, even in one locality

they get sand from Belgium. Their geological department has not taken it up yet, but they have some of the finest molding sands in the United States out there. In regard to silica sand, a very short way from them, there are some of the best silica sands located in Nevada, where there is nothing but rattlesnakes and silica sand. There is plenty there if they ever get railroad transportation.

A. A. GRUBB: It occurred to me that Mr. Smith possibly thought that the work we did a year or so ago had been laid aside as not being worth while. It may be of interest to you to know that at the Ohio Brass Company we have felt that the reclamation work which we carried on in the brass foundry paid us so well that during the past year we have repeated similar experiments in our malleable foundry. We are just now about to put in a plant that will cost us between $4,000 and $5,000, on which we are expecting to make a saving of at least $2,000 a year, basing the figures on the results which we have obtained in our brass foundry and on the experiments which we have carried on in the malleable foundry. During the same period that we have made this saving in sand we have made a reduction in the losses.

A. ROBERTSON: In the conservation of sand I have been wondering whether this committee has established any amount of pounds of sand that should be used per ton of steel castings for different grades? As steel men, we do not know (otherwise than from our own reports), how many pounds of sand we should use per ton of castings, and what would be a conservative figure to use per ton of steel castings. If we had an idea of that we would know then whether we were conserving our sand or not; it would give us some figure to shoot at.

R. F. HARRINGTON: If I recall correctly, two years ago there were about 5,200 questionnaires sent out to the various foundries in the country in an endeavor to obtain the very fact you have inquired about. Those questionnaires were so incompletely filled out it was impossible for the committee to determine what the average was or anywhere near it. There were only about 10 per cent of the foundries that replied that had any real knowledge of what they were using and who replied in such a manner that the data was available from which to draw some definite conclusions.

R. A. BULL: It occurs to me that to get some useful information on the points Mr. Robertson has touched upon that the committee might study the desirable sketch of the facing layer as related to the depth of additional sand in a flask, which is commonly termed backing sand in some kinds of foundry work. I think there is some difference of opinion among foundry men as to how deep the facing ought to be. Some foundries have given the matter a great deal of study and are trying to determine quite definitely how thick that layer of facing ought to be next to the pattern, in order to give just as good results as a layer that might be, say, four or five times as thick. In other words, the ratio of the facing

sand as related to the backing sand is an important factor in that total consumption; also, of course, the nature of the work you are producing. Perhaps the committee might sometimes have an opportunity to give some consideration to these points.

Mr. STONEHAM: I remember some time ago it was claimed that the round grains of sand were best fitted for the surface of a mold. In reclaiming the sand, I would like to ask the committee if they have found that by the breaking up of these grains into sharp corners, whether it is just as good as the round grains?

R. F. HARRINGTON: The gentleman has asked a very pertinent question, one that many people are not agreed on. Certainly first of all as to whether the round grain, to begin with, is more satisfactory than an angular grain sand, secondly whether when sand is reclaimed whether the grain becomes rounded or otherwise, and if it becomes more angular, whether or not, it has an ill effect upon the surface of the mold? I cannot speak as chairman of this committee from any data that the committee has on that particular subject. I think, however, from my own experience and my contact with other men who are engaged in conservation work, that I can state that in the use of molding sand substitute or in any reclamation or conservation work, that when the grains do become more angular because of the breaking up of those grains that we have not been able to see any ill effect from that change. I am going to ask, Mr. Grubb, who has done a great deal of work along those lines, to comment upon it.

A. A. GRUBB: Especially in the brass foundry, the temperatures seem to be so low that we have not been able to see any breaking up of the grains. In the malleable foundry, I believe, although I am not so certain of the statement, I believe that we have no such effect. I say I believe, because our experiments have been going on only over a period of about eight months, and under the microscope I can see no difference, no fracturing of the grains, but I would hesitate to draw final conclusions without further practical tests

A MEMBER: In answer to the gentleman's question, we have reclaimed sand for steel castings. We have used the reclaimed sand without any new sand in it at all, and have used about 60 per cent reclaimed. There is 40 per cent less bonding material in the reclaimed sand than we have in the new sand. Also we have let molds stand for sixteen hours, green sand molds, and the castings turned out from those molds were just as good as the new sand. As far as the broken grains I am not sure but I have looked through the microscope myself and could see no difference between the new sand and the reclaimed.

A MEMBER: I asked the question because there was so much stress laid on the round grains of sand some time ago, and I tried it out myself by making a mold of all new sand, trying to get it as near round as

possible and crushing some of the old sand with a rammer, and placing the sands side by side in the same mold, and I could not find any difference.

D. W. TRAINER: It is known that mineral quartz at times has either liquid or gaseous inclusions. Any of the heats that quartz grains are subjected to in steel casting, I believe, are not much greater than 1500 degrees Cent. Ordinary quartz grains without these inclusions, are not liable to break down before 1700 degrees, so I imagine there would be very little breaking down of the quartz grains in steel sands.

H. W. DIETERT: The experience we have had in coarse molding sand for sections up as high as a thousand pounds, has been that whenever we had coarse molding sand in which the sand grains were not silica or contained other grains than silica or quartz they did break up. I noticed particularly in one sand that these sand grains deteriorated quite rapidly, that is, within six months, the sand was about half as fine, but we have since then tried silica sand grains and mixed a very high bonding molding sand with it. This has only gone on two months now and we are keeping a fineness check on it and have noticed no cracking of the sand, but we have found that some of the very coarse molding sands do break up in sand grain structure. It seems that for large work there is a field for silica sand mixed with a very high bonded molding sand or clay product.

E. W. SMITH: There was a point there the committee brings out, a substitute for molding sand; I think that is a little misleading. Does the committee really mean a substiute for molding portions or for bonding portions of the sand?

R. F. HARRINGTON: I think possibly Mr. Smith's point is well taken although we thought when we used the term we did that it covered pretty well the substitutes for new molding sand, for loam and the substitutes for any bonding material.

R. F. BULL: A substitute would be, for instance,. a farinacious binder, or any liquid binder or any one of the ingredients you ordinarily find in molding sand?

R. F. HARRINGTON: Yes, sir.

CHAIRMAN SAUNDERS: We have as a visitor this afternoon a gentleman who is well known in England, and I may add, as fully well known in this country, who is a member of the British Cast Iron Research Association, and I am going to ask Mr. Fletcher if he will make some comment on the molding sand situation.

J. F. FLETCHER: I am very much pleased to take part in your discussion this afternoon, although I am afraid I must face it from quite another viewpoint than yours. The question that has just been raised is one that is occupying, I suppose, every sand research man's attention, whether the sand grain does actually break up or not. In our country we have to

deal with some sands where the main grains are not entirely silica. When they are composed of certain material we find that those sand grains, when applied to steel molding, do break up. That confirms the last speaker's point. Generally in our iron and brass founding sand we find that the grain loses its original rounded form. Most of our natural bonded sand have rounded contours and have their bond generally ferruginous and strongly so.

Talking about substitutes, I was early employed in the steel foundry industry and in those early days we never used any sand at all, we simply ground up our old crucibles, fire bricks, etc., and for many years never used any sand at all. It is a rather interesting commentary on the reverse position; that is to say we were then using synthetic sand, and now in England those old crucibles are no longer available and we have to resort to a mixture of naturally bonded molding sand and such of these other refractory materials as we can get.

For such reasons I can assure you that those of us who are interested in sand research on our side, are intensely interested in your work. You have gone far beyond our work, inasmuch as you have co-ordinated that work and given us many valuable ideas as to the work we can carry on. We are on the same track and are using your apparatus that we brought from here and with the greatest success, but we hope to let you have some of the results from the work we are doing on our side on the same subject you are on. Possibly in a year's time you will have some of the results of the work we have been able to do on sands which are more regularly obedient to our molder's demand than some of yours. I have seen some of your sands and I am afraid we should consider that it was a pretty hard job, that is, to get the finish that some of our English engineers demand on castings with such sand as you have in some of your neighborhoods.

I have seen some of the work that has been done in heavy and light foundries here, and in some foundries where sand research has been carried on at work, I have noticed that the surfaces of the castings are far better than in those plants where it was very evident no sand research investigation was going on. I am sure you have every reason to pat yourselves on the back for the work that is being done by your association.

Report of the Sub-Committee on Geological Survey

To the members of the American Foundrymen's Association:

At the Milwaukee convention, the chairman of the Geological Survey Sub-Committee reported that 728 sands from 11 different states had been tested, and that a number of additional ones had been received, but not yet tested.

Since that time a number of additional samples have been received, a portion of which have been tested, so that the situation at present is as follows:

State	Additional samples tested	Samples received not yet tested
Pennsylvania	31	29
New York	..	34
Maryland	..	35
Tennessee	..	61
Georgia	49	..
North Carolina	12	..
New Jersey	6	..
Iowa	12	..
Kentucky	24	..

It is expected that some additional samples will be sent in from Iowa which were collected this field season.

The only three important states in the eastern half of the United States, whose sand resources have not been officially investigated, are Missouri, Ohio and Indiana, but there has been no intimation from the state geologists of any of these states that they were ready to cooperate with the American Foundrymen's Association research committee.

The Chairman of your committee has written letters throughout the year to the different state geologists in regard to the importance of having tests made of the molding sands of their states, and of the opportunity of having these tests made without cost to them by the American Foundrymen's Association.

In addition to the states listed above as having collected molding sand samples during the year, the state geologist of West Vir-

ginia has collected a number of samples, but it has been decided to send these samples to the testing laboratory of the University of Cincinnati. It is hoped that additional work by your committee will induce the state geologists of the states which have not yet cooperated to send in samples for testing.

Your committee would like to be informed as to whether or not your association feels that an intensive study should be made of the molding sand resources of the states of the far West, as in this section of the country there are few large foundries.

Without the helpful suggestions and intense interest shown in the work of your committee by Doctor H. Ries, of Cornell University, and the full cooperation which he has given us, it would have been impossible to have progressed very far in these investigations.

Respectfully submitted,

WILBUR A. NELSON, *Chairman,*
Sub-Committee on Geological Survey.

October 6, 1925.

Report of Certain Molding Sand Resources of Georgia, Iowa, Kentucky, New Jersey, North Carolina, Pennsylvania and Wisconsin*

Issued by The Joint Committee on Molding Sand Research

Georgia

Lab. No.: 1301.
Location: One mile southwest of Emerson, Bartow County, a station on Western and Atlantic Railroad.
Producer: West Stancel.
Formation: Weisner quartzite of Cambrian. The sand occurs in a series of small deposits of a few cubic yards each, resulting from the weathering of the quartzite. Three or four acres approximately are underlain by these deposits, covering the entire slope of a wooded ridge. The overburden is negligible.
Grade: For casting small cog-wheels, washer plates and other pieces of mine machinery.

Lab. No.: 1302.
Location: One and one-half miles north of Flint-Stone, Walker County, on the Tennessee, Alabama and Georgia Railroad.
Producer: F. A. Crutchfield.
Formation: Flood plain deposit in valley underlain chiefly by the Chickamauga limestone. The deposit covers a large acreage, and varies in thickness from one to six feet. It was lain down by one or more creeks apparently, and its lower boundary everywhere is marked by a deposit of medium-sized water worn boulders.
Grade: Principally in the Chattanooga foundry of the U. S. Cast Iron Pipe and Foundry Company, for casting piping, etc.

Lab. No.: 1303.
Location: One-fourth mile south of Blowing Springs, Walker County, on Tennessee, Alabama and Georgia Railroad.
Producer: Morse Bros. Company.
Formation: Flood plain deposit in valley underlain mainly by Chickamauga limestone. The deposit covers about 12 acres, to a depth of 2 to 3 feet. The overburden consists of a foot of sandy loam, while sharp sand underlies the deposit.
Grade: Used especially for heavy iron castings at the Jones Machine and Foundry Co. foundry in Chattanooga.

Lab. No.: 1304.
Location: Three miles southeast of Ringgold, Catoosa County, on Western and Atlantic Railroad.
Producer: Fred Warmack.
Formation: Flood plain deposit in valley underlain by Chickamauga limestone. The sand covers at least 15 acres, with a maximum

*This report is supplementary to the report as presented by the committee before the 1924 Milwaukee meeting. Additional data will be issued as the results of tests from other samples are secured.

thickness of 3 feet. One foot of gray, loamy soil forms the overburden, while coarse quartz sand occurs beneath the deposit.
Grade: Used for plow points, etc., at the Chattanooga Plow Works.

Lab. No.: 1305.
Location: Four and one-half miles southeast of Ringgold, Catoosa County, on Western and Atlantic Railroad. Nearest siding, Greenwood, one-half mile distant.
Producer: William Black.
Formation: Flood plain deposit in valley underlain by Chickamauga limestone. Deposit covers about 5 acres, with maximum thickness of 8 feet, but will not average over 5 feet. A foot of loamy soil forms the overburden. It occurs along the west bank of E. Chickamauga Creek.
Grade: For casting gray iron in the Ross-Meehan foundry in Chattanooga; in the Chattanooga Plow Works, and some years ago at the Fairbanks Scale Works, Rome, Ga.

Lab. No.: 1306.
Location: Polk County 4½ miles northwest of Cedartown, on Cave Springs Road.
Producer: Property of Commercial Bank.
Formation: Knox Dolomite. Sand occurs apparently in small deposits, covering 2 to 3 acres altogether. It is of flood plain origin, made up of two separate beds, the upper 18 inches thick, and the lower 2 feet thick. Sample No. 1306 was taken from the lower bed, and sample No. 1307 from the upper bed. The overburden consists of 8 inches of sandy soil.
Grade: Used for all kinds of castings, including those of brass in foundry of the Cedartown Foundry and Machine Co.

Lab. No.: 1307. Same data as Lab. No. 1306.

Lab. No.: 1308.
Location: Just northeast of Terminal Station, Columbus, Muscogee County.
Producer: Golden Foundry and Machine Company.
Formation: Archaean. The deposit is not large enough for commercial exploitation. It occurs in one of the old Chattahoochie River terraces, which now is a part of the City of Columbus and largely occupied by houses.
Grade: For cores and rough iron castings in foundries of the Golden Foundry and Machine Company, the Columbus Iron Works, and in the Pekor Foundry.

Lab. No.: 1309.
Location: Just south of the City along east bank of Chattahoochee River.
Producer: Property of City of Columbus, known as the Common.
Formation: Cretaceous. The sand occurs in two beds, the upper with a maximum thickness of 2½ feet, and the lower with a thickness of about 3 feet. It underlies several acres but only a small area may be developed. It is of flood plain origin. Sample No. 1309 was taken from the upper bed and sample No. 1310 from the lower.
Grade: Used for medium sized iron castings, or mixed with sharp sand for cores.

Lab. No.: 1310. See data for Lab. No. 1309.

Lab. No.: 1311.
Location: Terrace in northern section of City of Columbus.
Formation: Archaean. The deposit is a very small one, in a settled portion of the city and therefore of no commercial importance. It evidently is a terrace deposit.

Lab. No.: 1312.
Location: One mile northwest of Cusstea, Chattahoochee County, on the Seaboard Air Line Railroad.
Producer: William Jones property.
Formation: Cretaceous. The deposit ranges from 3 to 12 feet in thickness, and underlies about 10 acres of a gently sloping ridge. It is a residual sand from the Cretaceous beds of the Fall Line Hills.
Grade: Has not been tested or used in foundries.

Lab. No.: 1313.
Location: Near Howard, Talbot County, on the Central of Georgia Railroad.
Producer: Central of Georgia Sand Company property.
Formation: Cretaceous. The sand may be said to occur in practically inexhaustible quantities, in so-called sand hills. Sample No. 1313 was taken from a bed about ⅓ foot in thickness at the base of the section, while sample No. 1314 represents the average product above, often 30 feet thick.
Grade: For "pig-beds" and building purposes.

Lab. No.: 1314. See data for Lab. No. 1313.

Lab. No.: 1315.
Location: This sample was taken from a pile of washed sand at the pits of the Central of Georgia Sand Company near Howard.
Grade: Used for casting steel at the Glover Machine Works, Marietta, Ga.

Lab. No.: 1316.
Location: At Junction City, on the Atlanta, Birmingham and Atlantic Railroad.
Producer: L. T. Downs property.
Formation: Cretaceous. This particular deposit of sand seems to be a sort of segregation in a much larger one of a more impure product. It has been shipped with the other sand, however. It is about 8 feet thick, with a face of 120 feet in the pit. The overburden consists of 5 feet or more of impure, though merchantable sand.
Grade: Building purposes.

Lab. No.: 1317.
Location: Three miles southeast of Junction City on the Atlanta, Birmingham and Atlantic Railroad.
Producer: Central of Georgia Sand Company.
Formation: Cretaceous. This deposit also is in the sand hill belt along the Fall Line, and of very wide extent. The bed from which the sample was taken is 4 feet thick as exposed in the pit. A foot of dark sandy loam, containing carbonaceous matter overlies it.
Grade: For pig-beds and building purposes.

Lab. No.: 1318.
Location: Four miles southeast of Junction City on the Atlantic, Birmingham and Atlantic Railroad.
Producer: Moore and Acme.
Formation: Cretaceous. The sand occurs in a bed, 1 to 2 feet thick and underlying at least 10 acres. About 10 feet of building sand overlies it.
Grade: Not used at present.

Lab. No.: 1319.
Location: Two miles south of Gaillard on the Southern Railroad.
Producer: Allon Sand Company.
Formation: Cretaceous. The sand has been estimated by the company to underlie 75 acres. The bed is about 3 to 5 feet thick with an overburden of 1 to 2 feet of silty sand.
Grade: Building purposes.

Lab. No.: 1320.
Location: About 1¼ miles south of Gaillard on the Southern Railroad.
Producer: Atlanta Sand and Supply Company.
Formation: Cretaceous. The sand occurs in a bed 7 feet thick, underlying 15 acres at least. About 10 feet of building sand overlies it.
Grade: For molding steel in the foundry of the Glover Machine Works, Marietta, Ga.

Lab. No.: 1321.
Location: One to seven miles southwest of Americus near the Seaboard Air Line Railroad.
Producer: C. J. Clark property.
Formation: Probably Ocala limestone. The sand has been regarded as residual from the limestone and of very wide distribution. This particular plot covers about 10 acres. There are two distinct beds, the upper one about 10 feet thick (sample No. 1322) and the lower about 15 feet thick. (Sample No. 1321.)
Grade: Building purposes.

Lab. No.: 1322. See data for Lab. No. 1321.

Lab. No.: 1323.
Location: Albany Junction on the Atlanta Coast Line Railroad.
Producer: W. N. Pace property.
Formation: Wind blown, probably. The sand occupies a prominent topographic feature covering 400 acres, to a maximum depth of 30 feet. It is thought to have been piled up by the wind.
Grade: For silica brick.

Lab. No.: 1324.
Location: One and one-half miles north of Blakely.
Producer: Mrs. Mattie Powell property.
Formation: Claiborne, of the Eocene. The sand occurs in a bed 12 feet thick, overlain by 5 to 12 feet of red clayey sand. It underlies a large area, as it is part of a geological formation.
Grade: Sand-cement brick.

Lab. No.: 1325.
Location: Two miles east of Thomasville on the Atlantic Coast Line Railroad.

Producer: E. E. Mack and Son property.
Formation: Alum Bluff. The sand occurs in a bed 4 to 6 feet thick, a part of the Alum Bluff formation which covers a large area in this part of the state. A few inches of silty sand forms the overburden.
Grade: For stove grates and heavy iron castings often weighing 8,000 pounds.

Lab. No.: 1326.
Location: Right of way of Georgia Northern Railroad near Swift and Company plant in northwestern section of Moultrie.
Formation: Alum Bluff. The sand is similar to that sampled at Thomasville, being also a part of the Alum Bluff formation. Pits along the railroad show it to be 3 feet thick.
Grade: For all kinds of iron castings in the Moultrie foundries.

Lab. No.: 1327.
Location: Just northeast of Albany along the right bank of the Flint River.
Producer: Nelson Tift property.
Formation: Glendon formation. The deposit is of flood plain origin and covers a narrow strip along the river about 200 yards long and 100 feet wide, to a depth of 1 to 4 feet.
Grade: For light and medium weight iron castings, and also for brass castings.

Lab. No.: 1328.
Location: One-half mile west of Chatterton on the Atlanta, Birmingham and Atlantic Railroad.
Producer: I. N. Williams property.
Formation: Alum Bluff. The sand is part of a deposit extending across Coffee County, along Seventeen Mile Creek. This sand belt is one-fourth to three-fourths mile in width and 8 to 25 feet thick. It evidently was deposited chiefly by the wind.
Grade: For building purpose.

Lab. No.: 1329.
Location: One mile northeast of Lumber City, along Little Ocmulgee River.
Producer: Mrs. A. H. Mobley property.
Formation: Alum Bluff. The deposit was probably laid down by a stream. It covers several acres to a depth of 6 to 9 feet. About 6 to 8 feet of impure sand, suitable for building purposes, overlies it.
Grade: In manufacturing glass for soft drink bottles.

Lab. No.: 1330.
Location: At the Southern Railroad crossing of Ocmulgee River, southeast of Lumber City.
Producer: I. N. Cook property.
Formation: Alum Bluff. The deposit covers about 5 acres to a depth of 1 to 2½ feet. It is of flood plain origin. The overburden is negligible.
Grade: For bricks.

Lab. No.: 1331.
Location: At Odessa on the Southern Railroad, 7 miles southeast of Jesup.
Producer: Odessa Brick Company property.
Formation: Alum Bluff. The sand occurs in a bed 1½ to 2 feet thick. It is identical in mode of occurrence, etc., to the sands sampled elsewhere from the Alum Bluff formation.
Grade: For bricks.

Lab. No. 1332. This sample was taken from a pile of material dredged from the Savannah River along the wharves at the City of Savannah. It evidently occurs in large quantities and was thought to be of value by foundrymen.

Lab. No.: 1333.
Location: On branch road to sugar refinery, northwest of Savannah.
Producer: Right of way of Central of Georgia Railroad.
Formation: Satilla formation of Pleistocene. The sand occurs in a bed 1 to 3 feet thick. It is a part of the Satilla formation and widespread in occurrence. The overburden consists of 1 to 4 feet of surficial sand.
Grade: For iron and brass castings in all Savannah foundries.

Lab. No.: 1334.
Location: Southwest of Augusta, one-fourth mile from the Georgia Belt Railroad.
Producer: Hagler Brick Company.
Formation: Cretaceous. This sand, as a part of the Cretaceous formation, is practically unlimited in quantity. The thickness of the bed is 2 to 3 feet with 1 foot of dark sandy loam as overburden.
Grade: For bricks.

Lab. No.: 1335.
Location: Just southeast of Dublin along Oconee River.
Producer: J. H. Harcom property.
Formation: Glendon. The deposit is a part of the Glendon formation. The bed is about 2 feet thick, with a foot or so of silty sand as overburden.
Grade: For bricks.

Lab. No.: 1336.
Location: One mile east of Dublin on Macon, Dublin and Savannah Railroad.
Producer: Cleveland Pope property.
Formation: Glendon. The sand is probably wind blown. It covers several acres to a depth of 10 to 30 feet.
Grade: Building purposes.

Lab. No.: 1337.
Location: Along Ocmulgee River, at Milledgeville road crossing.
Producer: Property of City of Macon.
Formation: Archaean. The deposit has been put down by the river on a portion of its flood plain, which covers about 10 acres. The

sand apparently is nowhere over 3 feet thick and missing entirely at some point. Coarse building sand has been deposited upon it near the river bank.

Lab. No.: 1338.
Location: In area south of Macon along Ocmulgee River, and known as "The Swamp."
Producer: Property of Bibb Brick Company.
Formation: Cretaceous. The sand occurs in an area that has been extensively worked for brick clay, so that it necessarily occurs in small deposits, covering a large acreage altogether. The thickness of the bed is not over 3 feet, with little overburden.
Grade: For casting large and small iron pieces; for bricks.

Lab. No.: 1339.
Location: One mile east of Almon, on west bank of Yellow River.
Producer: Mrs. C. K. Gailey property.
Formation: Archaean. The deposit made up of two beds is of flood plain origin, and occupies a narrow belt along the river, about 300 yards long. The upper bed is 1 to 3 feet thick (Sample No. 1339), while the lower is 1 to 5 feet thick (Sample No. 1340). Building sand has been deposited upon them close to the river.
Grade: For molding both brass and iron castings.

Lab. No.: 1340. See data Lab. No. 1339.

Lab. No.: 1341.
Location: One-half mile northeast of Almon, on west bank of Yellow River.
Producer: W. S. Mabert property.
Formation: Archaean. The deposit covers about one acre to a depth of 2 to 3 feet. It is of flood plain origin, and similar to the sand described under Lab. No. 1340.

Lab. No.: 1342.
Location: Cut on Central of Georgia Railroad, one-half north of Porterdale.
Formation: Archaean. This sand, dark reddish in color, is a characteristic weathering product of Archaean rocks in north Georgia. It is often over 10 feet thick, and generally underlain by a mottled clay.

Lab. No.: 1343.
Location: Cut on Midland Railroad in Gainesville, near Southern Railroad depot.
Formation: Brevard schist (Cambrian). The sand is found over about 3 acres in the immediate vicinity. Its maximum thickness is about 4 feet. It is a residual product apparently.
Grade: For casting iron and brass in foundry of Gainesville Iron Works.

Lab. No.: 1344.
Location: One mile northeast of Bolton.
Producer: W. R. Lyons property.
Formation: Archaean. This deposit was probably laid down by the Chattahoochie River, though at present it is several hundred feet

below the level of the deposit. The sand underlies about 10 acres, to a depth of 1 to 5 feet.
Grade: Has been used in past years for casting iron in certain Atlanta foundries.

Lab. No.: 1345.
Location: On west bank of Chattahoochee River, at Mayson and Turner Road bridge.
Producer: Chattahoochee Brick Company.
Formation: Archaean. This is a sand also laid down by the Chattahoochee River. The bed is 2½ feet thick and occupies a belt about 100 feet wide, and 100 yards long, close to the river bank. Other deposits of a similar nature should occur north and south of this point. A coarse silty sand, not over 3 feet thick, overlies it.

Lab. No.: 1346.
Location: One mile northeast of Bolton.
Producer: W. R. Lyons property.
Formation: Archaean. This is a red residual sand, a weathered product of the Archaean rocks. It is common in north Georgia. It underlies the sand, described under sample No. 1344.

Lab. No.: 1347.
Location: One-fourth mile north of Utoy Creek, on Baker's Ferry Road, Fulton County.
Producer: Mrs. Joseph Wilson property.
Formation: Archaean. This is a deposit also laid down by the Chattahoochee River on the residual sands and clays of the Archaean rocks. The bed is 1 to 4 feet thick approximately.

Lab. No.: 1348.
Location: One mile south of Utoy Creek on Baker's Ferry Road.
Producer: Faris Campbell property.
Formation: Archaean. The sand occurs in a bed about 1 to 2 feet thick, a residual product of the Archaean rocks. It is overlain by 2 feet of silty sand and underlain by a mottled clay.

Iowa

Lab. No.: 1101.
Location: In N. E. ¼, of S. W. ¼, of S. 28, Marion Township, Marshall County. About 4 miles east of Marshalltown, near top of north bluff of Iowa River.
Producer: Lester William.
Formation: A buff calcareous loess, with concretions. Section exposed 10 feet thick, with 1½ feet soil overburden. C. G. W. R. R., ¼ mile distant.
Grade: Molding Sand used by foundries in Marshalltown.

Lab. No.: 1102.
Location: Near Prier foundry, Marshalltown.
Producer: W. H. Prier.
Formation: Deposit 5 feet thick, with 3 feet soil and subsoil overbur-

den. It is in a low, narrow, dune ridge, and the deposit contains inclined seams of brown, sandy clay, 1 or 2 inches thick.
Grade: Core sand used at Marshalltown Foundries.

Lab. No.: 1103.
Location: 300 yards north of Floyd station, Floyd Co.
Producer: Pit of P. J. Bennett.
Formation: Section shows:

1.	Soil and subsoil	3 feet
2.	Hardpan, tight, dry clay	1½ feet
3.	Loess (leached)	2 feet
4.	Loess (calcareous) exposed	4 feet

The sample is a mixture of 3 and 4.
Grade: Molding sand.

Lab. No.: 1104.
Location: The junction near Nora Springs, Floyd Co.
Producer: From Pit leased by the Hart-Parr Co., of Charles City.
Formation: Section shows about 3 feet of leached, sandy, loess under 2 feet of soil and subsoil, and with three 2 inch clayey streaks in the lower part of the deposit.
Grade: Molding sand used in Hart-Parr foundries at Charles City.

Lab. No.: 1105.
Location: Clinton, Iowa on Harrison Road.
Producer: F. A. Chinn.
Formation: The height of face is 15 to 30 feet, of which 1 to 2 feet is overburden. The deposit which underlies at least several acres, is on the flank of a hill, on the eastern margin of an abandoned valley of the Mississippi River. Railroad siding nearby.
Grade: Molding sand, used in foundries.

Lab. No.: 1106.
Location: Clinton.
Producer: Roadside pit on south side of P. E. Vosburg's property.
Formation: Section shows a 2 foot bed of molding sand, underlain by 4 feet of core sand, and covered by 2-3 feet soil and subsoil. It is at least 5 acres in extent and of eolian origin.
Grade: Molding sand.

Lab. No.: 1107.
Location: Cedar Rapids.
Producer: From pit of Iowa Steel and Iron Works at Oak Hill.
Formation: The section shows 12 feet of loess, on top of glacial drift.
Grade: Molding sand used in brass and aluminum casting, and for bench work in gray iron molding.

Lab. No.: 1108.
Location: North of Highland Park, Des Moines, near Saylor Center school.
Producer: Leon Harris' pit.
Formation: Sand is 2-4 feet thick and covered by 3 feet of soil and subsoil. Near bottom of deposit there are two 2 inch seams of coarser sand mixed with clay. The deposit is on a hill southeast

of the wide flood plains of the Des Moines and old Moingona River valleys. It is probably a wind formed deposit.
Grade: Molding sand.

Lab. No.: 1109.
Location: One mile southeast of Reasnor, Jasper Co., at a hilltop on short ridge on southeast side of a curve in Skunk River valley.
Producer: From pit on farm of Ben Lufkin.
Formation: About two feet of soil is stripped off, and the underlying 6 to 8 feet of loess and sand are sold for brass and alminum work. At a lower level in the same pit a 10 foot zone of slightly coarser and less clayey sand occurs, which is used for asphalt paving.
Grade: Molding sand used for brass and aluminum.

Lab. No.: 1110.
Location: Ottumwa.
Producer: From a pit located on a hillside near the end of Randolph Street.
Formation: The section shows 10 feet or more of sand covered by 10 to 12 feet of reddish clay. The sand is coarse, of red color.
Grade: Core sand used for cores in stove and furnace foundries, as well as other heavy work.

Lab. No.: 1111.
Location: Nearly opposite Heinz Manufacturing Company's plant at Muscatine.
Producer: From E. O. Burnside's pit.
Formation: The deposit is 5 to 8 feet thick, and covered with 5 feet of loess. It is of eolian origin, and rests on glacial till.
Grade: Molding sand.

Kentucky

Lab. No.: 1001.
Location: One-half mile from Ill. Cent. R. R., Princeton, Caldwell Co., Ky.
Producer: Max Spickard and Son.
Formation: Rock uniform textured, quartz grains, white color, with no lumpy inclusions, and non-calcareous. Working face 30 feet high. Friable sandstone.

Lab. No.: 1002.
Location: River sand, at southeast corner of City Park, Ashland, Boyd Co., and 5 blocks from C. and O. R. R.
Formation: Deposit worked as a pit with face 120 feet long and 20 feet high. Material of uniform texture except for one lens of fine sand about 10 feet long and 1 foot thick. Grains mostly quartz, bond clay and hydrous iron oxide.
Grade: Used for molding.

Lab. No.: 1003.
Location: Between Lexington and Bath Aves. and 25th and 26th Streets, and 7 blocks from C. and O. R. R., Ashland, Ky.
Producer: Norton Iron Works.

Formation: Deposit of cross bedded river sand is 40 feet thick, with 1 to 6 inch sod overburden. It is of uniform character, with little clayey matter. Grains mostly quartz non-calcareous and no lumpy impurities.
Grade: Used in Ashland as a molding sand.

Lab. No.: 1004.
Location: Between tracks and county road, just east of race track at Raceland, Greenup Co.
Producer: Property of C. and O. R. R.
Formation: Deposit of river sand with small gravel. Area of deposit about ⅛ by ¼ mile. Overburden 5 to 6 inches sod. Sand grains uniform and pebbles can be easily screened out. Material non-calcareous with little clayey matter or iron oxide.

Lab. No.: 1005.
Location: At north end of tracks at Raceland, 5 miles south of Greenup, Greenup Co.
Producer: Property of Kentucky Fair and Railway Transportation Co. of Ashland.
Formation: Deposit about ½ by ¼ mile, with sod overburden. Mainly silica sand of non-calcareous character, with little binding material.

Lab. No.: 1006.
Location: 2 miles S. W. of Ashland, Boyd Co., and 2 miles from C. and O. R. R.
Producer: Property of Tom Smith.
Formation: Disintegrated argillaceous and ferriginous sandstone. Covers about 6 acres with sod overburden. Deposit uniform, of non-calcareous nature, and considerable clay bond.
Grade: Used for molding sand.

Lab. No.: 1007.
Location: Eight miles north of Olive Hill, Carter Co. and on county road extending up Henderson Branch, at a point about 1 mile south of Lewis County line. Tramway within 1000 feet of deposit.
Producer: Property of Olive Hill Refractories Co.
Formation: Sandstone. The sandstone is at least 30 feet thick, of uniform texture, and with little overburden. Grains of rock mostly quartz, with scattered muscovite mica scales; non-calcareous. Said to crush easily.
Grade: At present used in manufacture of silica brick.

Lab. No.: 1008.
Location: At Bellevue, 1½ miles southeast of Newport and ½ mile from shipping point.
Producer: Pit of Newport Sand Bank Co., of Newport, Ky.
Formation: Texture of material uniform, with no lumpy impurities.
Grade: Used for molding. Known as 4-W.

Lab. No.: 1009.
Location: East side of Bellevue field.
Producer: Pit of Newport Sand Bank Co.
Formation: Sand deposit 2½ feet thick overlying clayey loam.
Grade: Clayey loam. Known as 5-W.

Lab. No.: 1010.
Location: East side of Bellevue field.
Producer: Pit of Newport Sand Bank Co.
Grade: Core sand. Known as F core.

Lab. No.: 1011.
Location: East side of Bellevue field.
Producer: Pit of Newport Sand Bank Co.
Formation: Deposit 9 feet thick with little overburden.
Grade: Known as 5-F.

Lab. No.: 1012.
Location: Bellevue field, west side.
Producer: Pit of Newport Sand Bank Co.
Grade: Known as 5-B.

Lab. No.: 1013.
Location: Same as 1012.
Grade: Known as 6-B.

Lab. No.: 1014.
Location: Cold Spring district, 10 miles southeast of Newport, Ky.
Producer: Pit of Newport Sand Bank Co.
Formation: Deposit 10-15 feet thick, with 1-2 feet overburden.
Grade: Known as 2 Red.

Lab. No.: 1015.
Location: Covington, Ky.
Producer: Schlosser Bros.
Formation: Deposit 20 feet thick.
Grade: Sand employed for general foundry work.

Lab. No.: 1016.
Location: Sperl Sand pit, Covington, Ky.
Producer: S. J. Moore.
Formation: Deposit 10 feet thick, with occasional pebbles, slightly calcareous.
Grade: Designated as No. 3 grade, and used for aluminum, brass, and small iron work.

Lab. No.: 1017.
Location: Same locality as 1016.
Formation: Deposit 10 feet thick, with 1 foot overburden.
Grade: Heavy loam sand said to be used for large castings.

Lab. No.: 1018.
Location: Mentor, Campbell Co.
Producer: T. O. Kennedy.
Formation: Deposit 12 feet thick, with 6 inches to 1 foot overburden, underlain by building sand.
Grade: No. 3.

Lab. No.: 1019.
Location: Carrollton, Carroll Co.
Producer: Carrollton Sand and Gravel Co.
Grade: White core sand.

Lab. No.: 1020.
Location: Same as No. 1019.
Producer: Same as No. 1019.
Formation: Gravelly sand which has to be screened.

Lab. No.: 1021.
Location: Same as 1019.
Producer: Same as 1019.
Formation: Deposit 5 feet thick, overlain by 6 feet heavy loam sand.
Grade: Red molding sand.

Lab. No.: 1022.
Location: Deposit at East View, Hardin Co.
Producer: Hermann Molding Sand Co., of Louisville.
Formation: A soft sandstone.
Grade: Sold to foundries.

Lab. No.: 1023.
Location: Louisville, Jefferson Co.
Producer: W. H. Cloud Molding Sand Co.
Grade: Molding sand.

Lab. No.: 1024.
Location: Same as 1023.

New Jersey

Lab. No.: 537.
Location: The deposit from which samples 537, 538, and 539 came is located on the broad flat, southwest of the depot of Delaware, Warren County.
Producer: Delaware Sand Company, Belvidere, N. J.
Formation: The material represents a river deposit made during flood stages of the Delaware River during late glacial times.
Grade: No. 1 Delaware sand. The sand is said to be used for large, medium and small iron castings as well as brass and aluminum.

Lab. No.: 538.
Producer: Same as 537.
Grade: 1 A Delaware sand.

Lab. No.: 539.
Producer: Same as 537.
Grade: No. 2 Delaware sand.

Lab. No.: 540.
Location: Clayville, Cumberland Co.
Producer: From pit of Daniel Goff Co.
Formation: Bridgeton marine, consisting of nearly horizontal stratified deposits. Sample from small pit in woods several hundred yards southeast from the main clay pit. The molding sand is 5 feet thick, overlain by 3 feet of soil, sand and gravel. Some clay streaks.

Lab. No.: 541.
Location: Same as 540. Pit is north of the middle of the spur track and near the washing plant.
Formation: Cohansey formation. Overburden 8 to 12 feet, chiefly material filled in from previous work. Working face nearly 20 feet

high. Upper half is of whitish sand with numerous fine laminae of yellowish sand; lower half nearly all a very fine grained white sand, with occasional lenses of yellow sand. Run of bank is washed, and resulting sand is cream colored. The sample tested represents the washed material obtained by sampling the stock pile.
Grade: Steel molding sand.

Lab. No.: 542.
Location: Same as 540.
Producer: Same as 540.
Formation: Material is the regular so-called Millville molding gravel and from Bridgeton Marine formation. Loads are hauled from different portions of the gravel pits, which are to the south of the middle of the spur track, to a loading platform, where they are mixed, screened and at once loaded onto the cars. The sample was obtained from different parts of the car. Sand said to have medium strong bond.
Grade: Millville molding gravel.

Lab. No.: 543.
Location: Millville. The sand and gravel plant extends for a half mile or more along Menantico Creek, at what was once known as Clark's Mill.
Producer: Menantico Sand and Gravel Co.
Formation: Material occurs in Cape May (Pleistocene) and Cohansey (Pliocene) formations, but the sample is chiefly from the former. The material is dredged, wet screened, dried, and dry screened. The sample represents fine steel molding sand, and represents end product of screening operation.
Grade: Steel molding sand.

Lab. No.: 544.
Location: Near Manumuskin, Cumberland Co.
Producer: New Jersey Silica Sand Company.
Formation: Cohansey (Pliocene) marine. Sand is dredged, washed and wet screened.
Grade: Sample represents No. 3 New Jersey Silica Sand, and was taken from stock pile. It is sold for steel molding and cores.

Lab. No.: 545.
Location: Same as 544. Sample taken from pit ⅛ mile N. of washing plant.
Producer: Same as 544.
Formation: In the bank, the materials are white or gray sand layers about 2 inches thick, alternating with yellow layers ½ inch thick.
Grade: Represents material about as shipped, and called Maurice River sharp silica sand.

North Carolina

Lab. No.: 1450.
Location: Germanton, Stokes County. Sand covers about 200 acres lying along Town Creek some 3 miles east of Germanton. Sample from west end of deposit and north side of creek.
Producer: R. C. Humphries and Charles Smith, Germanton.
Formation: Consists of sand and top soil from open field. Varies 1 to 3 feet deep.
Grade: None listed. Seems promising.

Lab. No.: 1451. Same data as Lab. No. 1450.

Lab. No.: 1452. Same data as Lab. No. 1450, except sample came from the east end of deposit and north side of creek on property of C. Smith.

Lab. No.: 1453. Same data as Lab. No. 1452.

Lab. No.: 1454. Same data as Lab. No. 1450, except sample came from south side of creek. A finer sand varying from 2 to 4 feet deep on property of R. C. Humphries.

Lab. No.: 1455.
Location: Cataroba River about 3 miles north of Mount Holly, N. C.
Producer: R. C. Belk.
Formation: Old river terrace. Deposit covers 40 to 50 acres varying in depth from 3 to 15 feet. Sample from north end of deposit where deposit is 4 to 6 feet in depth.
Grade: Not used at present.

Lab. No.: 1456. Same data as Lab. No. 1455, except sample came from east side of north end of deposit where deposit runs from 2 to 4 feet deep with apparently more clay than No. 1455.

Lab. No.: 1457. Same data as Lab. No. 1455, except sample taken from southern end of property where deposit varies 10 to 15 feet in depth.

Lab. No.: 1458.
Location: Bonsal property about 2 miles from railroad but near tram road at Lilesville.
Formation: Large deposits of red sand with weak bond which is found on the borders of large holdings of commercial sand and gravel.
Grade: Not used at present.

Pennsylvania

Note—Unless otherwise noted all samples were taken from pit.
Lab. No.: 631.
Location: Gulick farm 1 mile W. of Riverside, Northumberland Co.
Producer: W. W. Gulick, Danville.
Formation: Glacial lake or river deposit. Section shows: Soil, 12 inch; molding sand, 30-36 inches.
Grade: Medium-B. G. Used in foundries, boiler works, etc., for medium weight castings.

Lab. No.: 632.
Location: About 1½ miles W. of Riverside, Northumberland Co.
Producer: W. W. Gulick, Danville.
Formation: Section shows soil 10 inches, molding sand 5½ feet.
Grade: A-D. Used for stove plate and other light castings. Also brass and bronze.

Lab. No.: 633.
Location: About 1¾ miles W. of Riverside, Northumberland Co.
Producer: W. W. Gulick, Danville.
Formation: Section shows soil 1 foot, molding sand 6-9 feet.
Grade: AAA-G. Used for fine iron, brass and aluminum castings.

Lab. No.: 634.
Location: Grounds of State Hospital for Insane, at Danville, Montour Co.
Producer: W. W. Gulick, Danville.
Formation: Sand 3-10 feet deep.
Grade: AAA-H. Used for light ornamental iron and brass.

Lab. No.: 635.
Location: One mile S. W. of Bloomsburg and ½ mile N. W. of Rupert, Columbia Co.
Producer: W. W. Gulick, Danville.
Formation: Sand as developed shows a thickness of 2-9 feet.
Grade: AA-Selected. Used for stove work, other light iron castings and brass.

Lab. No.: 636.
Location: River bottom meadow at Emporium Junction, Cameron Co.
Producer: Oscar Heath, Emporium.
Formation: Sand is 3-5 feet deep and covered by a few inches of soil. Sample taken from stock pile.
Grade: Used for car wheels, acid pans (4500 pounds) and other machinery castings made in both green and dry sand molds. Has also been used for aluminum and brass.

Lab. No.: 637.
Location: Same as Lab. No. 636 but sample taken from pit.

Lab. No.: 638.
Location: Bank of Clarion River 5 miles W. of Ridgway, Elk Co.
Producer: Gardner Sand Co., Ridgway.
Formation: Deposit of river alluvium. Section shows soil 2 feet, molding sand 4-6 feet. Represents car sample.
Grade: Velvet No. 4. Used for radiators, brake shoes, malleable iron.

Lab. No.: 639.
Location: Five miles S. of Ridgway.
Producer: Gardner Sand Co., Ridgway.
Formation: Unwashed crushed sandstone. Sample from stockpile.
Grade: Steel foundry sand.

Lab. No.: 640.
Location: Five miles S. of Ridgway.
Producer: Gardner Sand Co., Ridgway.
Formation: Deposit 10 feet deep.
Grade: Loam.

Lab. No.: 641.
Location: From shore of Lake Erie, 3½ miles W. of Springfield.
Producer: Walker Sand Co., West Springfield.
Formation: A glacial lake deposit. Section shows 3 feet sand covered by sod.
Grade: No. 1-V. Used for stove plate, high grade malleable castings.

Lab. No.: 643.
Location: Five miles S. of Ridgway.
Producer: Gardner Sand Co., Ridgway.
Formation: River alluvium.
Grade: No. 1.

Lab. No.: 644.
Location: Three and one-half miles N. E. of West Springfield.
Producer: Walker Sand Co., West Springfield.
Formation: A glacial lake deposit covering acres of flat land. Section 2 feet thick, just under sod in higher parts of fields.
Grade: No. 1-H. Used for malleable iron and cores.

Lab. No.: 645.
Location: Same as No. 644.
Producer: Same as No. 644.
Grade: No. 3-E. Used by gray iron foundries for medium and heavy castings.

Lab. No.: 646.
Location: One and one-half miles W. of Fairview, Erie Co.
Producer: Same as No. 644.
Formation: Two and one-half feet deep just under sod. Small gravel with bond.
Grade: No. 6-FV. Used for ingot molds and cores.

Lab. No.: 647.
Location: One and one-half miles N. E. of West Springfield.
Producer: Enterprise Sand Co. of Pittsburgh.
Formation: A glacial lake deposit. Sample taken from car.
Grade: 1½ Hoxie. Used for bath tubs, and other sanitary ware, plows and general light casting work.

Lab. No.: 648.
Location: Undeveloped deposit by Lakeside hotel, Northeast, Pa.
Formation: Molding sand 5-8 feet below surface in beach bluff of Lake Erie. Sample cut from bluff represents four feet of the section. Probably underlies many acres but at depth of several feet.

Lab. No.: 649.
Location: Pit on J. L. Pfaff farm 1 mile S. of Atlantic, Pa.
Producer: Superior Sand Co., Cleveland, O.
Formation: Strip off 3-5 feet of glacial drift, and then dig 20 feet of sand.
Grade: Used for various iron work, and also bronze.

Lab. No.: 650.
Producer: Greenville Silica Products Co., Greenville.
Formation: Crushed and washed sandstone. Sample from stockpile.
Grade: "High fuse." Sold to steel works.

Lab. No.: 651.
Producer: Same as 650.
Formation: Same as 650, but finer grained material. Sample from stockpile.

Lab. No.: 652.
Producer: Same as 650.
Formation: Fine sand and clay representing the material settled out from first run of wash water. Sample from settling pond.
Grade: Sold to foundries.

Lab. No.: 653.
Location: Quarry 1½ miles S. W. of Polk.
Producer: Dick Sand Co., Franklin.

Formation: Represents unwashed crushed sandstone. Sample from stockpile.
Grade: Sold to steel foundries.

Lab. No.: 654.
Location: Terrace deposit along Alleghany River, at Colbert Ave., 10th ward, Oil City.
Producer: G. A. Ready, Oil City.
Formation: Sand 3-6 feet deep exposed, but said to be 30 feet thick. Is mottled red loam above and gray sand below. These are mixed and shipped to different iron foundries.
Grade: No. 2. Used in iron foundries including radiator works.

Lab. No.: 655.
Location: Same as 654.
Formation: Fine grained yellowish sand, taken from lower edge of same lots along railroad. It probably underlies 654. Undeveloped.

Lab. No.: 656.
Producer: Falls Creek Sand and Stone Co., Falls Creek.
Formation: Crushed sandstone, unwashed. Sample from stockpile.
Grade: Sold to steel companies.

Lab. No.: 657.
Producer: Same as 656.
Formation: Represents washed sand. Stock pile sample.

Lab. No.: 658.
Producer: New York and Pennsylvania Clay Products Co.
Formation: Sand stone crushed, ground and screened to different sizes.
Grade: Coarse sand used by American Car Wheel Co.

Lab. No.: 659. Same data as No. 658.

Lab. No.: 660. Same data as No. 658 except grade.
Grade: Used for general jobbing iron castings.

Lab. No.: 661. Same data as No. 658 except grade.
Grade: Used for general jobbing iron castings.

Lab. No.: 662. Same data as No. 658 except grade.
Grade: Used for brass and stoveplate work.

Wisconsin

Lab. No.: 801.
Owner: Caveney & Co., 1026 Milwaukee Ave., Milwaukee.
Formation: Glacial lake deposits. The beds have a lateral extent along the lake front of about ¼ miles, and are known in cellar excavations, and one pit where some material has been removed. Main bed about 2 feet thick.
Grade: For light casting.

Lab. No.: 802.
Owner: H. Gloede, Jr., 2022 N. Wisconsin St., Racine, Wis.

Formation: Glacial lake deposits. The sand extends along the lake shore about ¼ mile north and south, and about 200 yards back in the lake. Molding sand 18 inches to 2 feet thick.
Grade: Medium to light casting.

Lab. No.: 803.
Owner: H. Gloede, Jr., 2022 N. Wisconsin St., Racine, Wis.
Formation: Glacial lake deposits. The core sand occurs below the molding sand mentioned in Lab. No. 802.
Grade: Core sand.

Lab. No.: 804.
Owner: Walsh Sand & Gravel Co., Burlington, Wis.
Formation: Ground moraine of the Lake Michigan glacial lobe. The sand is 18 inches to 2 feet thick and has a probable extent of 15 to 20 acres.
Grade: This pit just recently opened. Sand being used for medium to light weight castings.

Lab. No.: 805.
Owner: Walsh Sand & Gravel Co., Burlington, Wis.
Formation: Terrace above the Rock River. This pit has been worked for some time, but there appears to be 80 to 100 acres of material having a maximum thickness of 3 feet.
Grade: Heavy castings and cupola clay.

Lab. No.: 806.
Owner: Richter Farm, operated by the Garden City Sand Co., of Chicago, Ill.
Formation: Terrace material above the Rock River. Several pits have been worked from time to time in this vicinity. The pit sampled covers about 100 acres and a maximum thickness of the sand is 2 feet.
Grade: Heavy casting.

Lab. No.: 807.
Owner: Ben Eleverman, Basset, Wis.
Formation: Terminal moraine material. This pit is not very extensive, 15 acres probably the maximum. Sand varies in thickness.
Grade: Various kinds of light and medium work.

Lab. No.: 808.
Owner: Brother of Ben Eleverman, Basset, Wis.
Formation: Terminal moraine material. The deposit is about 10 acres in extent, and the sand has a thickness of 2½ to 3 feet.
Grade: Sand not used.

Lab. No.: 809.
Owner: William Perrigo, 8 Emerson St., Beloit, Wis.
Formation: Recent terrace material. There seems to be about 15 or 20 acres still remaining in this pit. The sand varies in thickness from 4 to 5 feet.
Grade: Medium to heavy castings.

Lab. No.: 810.
Owner: Same as Lab. No. 808.
Formation: Same as Lab. No. 809. There seems to be a small pocket of this material near the center of the pit.
Grade: Light weight castings.

Lab. No.: 811.
Owner: Guetschow Bros. Sand Co., R. R. No. 1, Box 2, Beloit, Wis.
Formation: Fossil dunes on a high terrace above the Rock River. This deposit is not very extensive. The sand occurs in small knobs about an acre in extent.
Grade: Core sand.

Lab. No.: 812.
Formation: This is a sample of Rockton, Ill., sand used at the Fairbanks Morse Company at Beloit, Wis.

Lab. No.: 813.
Owner: William Keyes, Madison, Wis.
Formation: Laminated delta sands. There are several beds about a foot thick in this pit which is principally worked for building sand which might be used for core work.
Grade: Has been used some locally for core work.

Lab. No.: 814.
Owners: Doctors Pember and Nuzum, operated by Janesville, Wisconsin, Molding Sand Company, Inc., Janesville, Wis.
Formation: Outwash terrace material. The two grades of sand represented by 814 and 815 occur over about 100 acres. The general thickness of the material is about 2 feet.
Grade: Medium to heavy castings.

Lab. No.: 815.—Same as No. 814.

Lab. No.: 816.
Owner: Christian Washmuth, Dousman, Wis.
Formation: Outwash terrace material. Fifty acres of sand, 18 inches in depth, still remain in this pit.
Grade: Heavy castings.

Lab. No.: 817.
Owner: Not determined.
Formation: Outwash terrace material. The actual extent of this deposit is not known, but it would appear from the topography to have an extent of about 40 acres.
Grade: Sand not used.

Lab. No.: 818.
Owner: Part of this deposit is on the property of the Chicago and Northwestern Railroad.
Formation: Moranic ridge. About 10 acres of material, 15 feet thick, covered by an overburdened of till and gravel 3 feet thick.
Grade: Sand not used.

Lab. No.: 819.
Owner: This deposit was worked by Otto Lange, of Sheboygan, Wis.
Formation: Beach sand. The locality where the sand is taken from the lake shore extends about ½ mile along the shore at the water's edge.
Grade: The sample is used for cores, but a coarser grade may also be used as a blast sand.

Lab. No.: 820.
Owner: James Nohn, operated by Joseph Bardouche, Green Bay, Wis.
Formation: High terrace above Green Bay. Ten acres 2 to 3 feet thick. The core sand underlies the molding sand in places.
Grade: Medium weight castings and cores.

Lab. No.: 821.—Same as 820.

Lab. No.: 822.
Owner: Ben Shultz, R. R. No. 9, Neenah, Wis.
Formation: Terrace material west of the city of Neenah, Wis. About 30 acres of sand, 2 to 3 feet thick, still remain in this deposit. The core sand undelies the molding sand in several places.
Grade: Brass, aluminum and light iron molding; also core sand.

Lab. No.: 823.—Same as 822.

Lab. No.: 824.—Same as 822.

Lab. No.: 825.—Same as 822.

Lab. No.: 826.
Owner: Not determined.
Formation: Sand occurs in what appeared to be large dunes. This material is very extensive both east and west of the village of Hortonville, Wis.
Grade: Not used.

Lab. No.: 827.
Owner: Green Bay & Western Railroad.
Formation: Small kame terrace. Two or 3 acres of sand about 2 feet thick.
Grade: Molding sand not used.

Lab. No.: 828.
Owner: The owner of the property where the sample was taken was not determined, but it is directly across the road from property owned by O. L. Olsen.
Formation: Recent terrace deposit. Two feet of sand covering about 5 acres.
Grade: Molding sand not used.

Lab. No.: 829.
Owner: Wheeler Mix, Berlin, Wis.
Formation: Moraine of the Green Bay glacier. Ten acres 5 to 8 feet thick.
Grade: Core sand.

Lab. No.: 830.
Owner: J. E. Mix Sand Co., R. R. No. 2, Berlin, Wis.
Formation: Glacial lake deposit. No. 830, beach deposit. No. 831, lake bottom deposit. The core sand covers about 15 acres, 8 to 12 feet thick. The acreage of the molding sand was not determined.
Grade: No. 830, core sand. No. 831, unused for molding sand.

Lab. No.: 831.—See No. 830.

Lab. No.: 832.
Owner: Nathan Kintz; operator, Nathan Kintz Sand Co., Berlin, Wis.
Formation: Glacial lake deposit. No. 835, beach deposit. Numbers

832, 834 and 836 lake bottom deposits. There is about 100 acres of molding sand varying in thickness from 1 to 3 feet, according to the grade, and about 15 acres of core sand 8 to 10 feet thick.
Grade: No. 832 is No. 3 light molding sand. No. 836 is heavy molding sand, and No. 834 is No. 1 light molding sand. No. 835 is core sand.

Lab. No.: 833.
Owner: C. A. Zamzow, Berlin, Wis.
Formation: Glacial lake deposit. There are not more than 5 acres of this pit left. 2½ to 3 feet thick.
Grade: Medium to light molding sand.

Lab. No.: 834.—See No. 832.

Lab. No.: 835.—See No. 832.

Lab. No.: 836.—See No. 832.

Lab. No.: 837.
Owner: Frank Duberstein, R. R. No. 4, Berlin, Wis.
Formation: Glacial lake deposit. There were originally about 40 acres of sand in this deposit. There are now 15 acres of material 1½ to 2 feet thick.
Grade: No. 837, No. 1 light molding sand. No. 838, No. 3 heavy molding sand.

Lab. No.: 838.—See No. 837.

Lab. No.: 839.
Owner: Henry Traugett; operator, White & Traugett Co., Berlin, Wis.
Formation: Glacial lake deposit. Twenty acres, 1½ to 2 feet thick.
Grade: No. 839, grade No. 1 molding sand. No. 840, grade No. 2 molding sand.

Lab. No.: 840.—See No. 839.

Lab. No.: 841.
Owner: Henry Traugett.
Formation: Glacial lake deposit. Fifty acres of sand 2 to 3 feet thick.
Grade: Heavy molding sand.

Lab. No.: 842.
Owner: Hunt Bros.; operators, Northern Sand Co., Berlin, Wis.
Formation: Glacial lake beach deposit. Eight or 10 acres.
Grade: Light molding sand.

Lab. No.: 843.
Owner: Hunt Bros.; operators, Northern Sand Co., Berlin, Wis.
Formation: Glacial lake deposit. Nos. 843 and 844, bank sand. Nos. 845 and 846, milled sands. About 30 acres of sand varying from 2 to 3½ feet in thickness.
Grade: No. 843, grade No. 2; No. 844, grade No. 3; No. 845, grade No. 2 milled, and No. 846, grade No. 3 milled.

Lab. No.: 844.—See No. 843.

Lab. No.: 845.—See No. 843.

Lab. No.: 846.—See No. 843.

Lab. No.: 847.
Owner: Ray Otto.
Formation: Glacial lake deposit. About 30 acres of sand 2½ to 3½ feet thick, including all grades.
Grade: No. 847, No. 1 molding sand; No. 848, No. 2 molding sand; No. 849, No. 3 molding sand.

Lab. No.: 848.—See No. 847.

Lab. No.: 849.—See No. 847.

Lab. No.: 850.
Owner: Henry Hauschultz; operated by Ted Schier.
Formation: Glacial lake beach deposit. The sand will vary in thickness from 2 to 20 feet across the section of the beach, and has a lateral extent of about 8 to 10 acres.
Grade: Core sand.

Lab. No.: 851.
Owner: Miss Lillie Leuck, Ripon, Wis.
Formation: St. Peter sandstone. This formation outcrops in two quarry faces 25 to 30 feet in height.
Grade: Core and steel sand.

Lab. No.: 852.
Owner: Property directly east of the Ripon Limestone Co.
Formation: St. Peter sandstone. Small quarry face about 25 feet high and 100 feet wide.
Grade: Core and steel sand.

Lab. No.: 853.
Owner: Mr. and Mrs. Paul Kurkowski, leased and operated by Wisconsin Mineral Mining Company.
Formation: Glacial lake beach deposit. Fifty or 60 acres at least 5 feet thick.
Grade: Core sand.

Lab. No.: 854.
Owner: Mr. and Mrs. Antoni Nowak, leased and operated by Wisconsin Mineral Mining Company, Berlin, Wis.
Formation: Glacial lake beach deposit. Four to 5 feet deep, covers about 12 acres.

Lab. No.: 855.
Owner: Wisconsin Granite Co. and Joe Moeul, leased by Wisconsin Mineral Mining Company.
Formation: Glacial lake beach deposit. Five to 8 acres, 3 to 4 feet thick.
Grade: Core sand.

Lab. No.: 856.
Owner: H. G. Baehr & Sons, R. R. No. 4, Berlin, Wis.
Formation: Glacial lake beach deposit. Ten acres, 8 to 10 feet thick.
Grade: Core sand.

Lab. No.: 857.
Owner: Leased by Wisconsin Mineral Mining Co., Berlin, Wis.
Formation: Glacial lake beach deposit. Ten acres, 5 to 6 feet thick.
Grade: Core sand.

Lab. No.: 858.
Owner: Godwin Estate, operated by the Wisconsin Mineral Mining Co., Berlin, Wis.
Formation: Cambrian sandstone. One hundred foot quary face, 40 feet high.
Grade: Not used.

Lab. No.: 859.—Same as 858.

Lab. No.: 860.—Same as 858.

Lab. No.: 861.—Same as 858.

Lab. No.: 862.
Owner: Jacob Ihemen, leased by Wisconsin Mineral Mining Co., Berlin, Wis.
Formation: Recent terrace above the Fox River. Thirty to 40 acres, 8 to 10 feet thick.
Grade: Not used; coarse grade of core sand.

Lab. No.: 863.
Owner: Albert Gelhar.
Formation: Glacial lake deposit. No. 863, beach deposit, and No. 864, lake bottom deposit. Twelve foot face of bank core sand covering 40 acres; 10 to 15 acres molding sand.
Grade: Core sand and molding sand.

Lab. No.: 864.—See 863.

Lab. No.: 865.
Owner: Charles W. Kuehn, Fairwater, Wis.
Formation: St. Peter sandstone. Small quarry face, 12 feet high.
Grade: Core work.

Lab. No.: 866.
Owner: Pacific Sand Company, Portage, Wis.
Formation: Cambrian sandstone. Large quarry covering sever acres. Height of face, 20 to 30 feet.
Grade: Core work. No. 866, pit run. No. 867, crushed product.

Lab. No.: 867.—See 866.

Lab. No.: 868.
Owner: Pacific Sand Company, Portage, Wis.
Formation: Terminal moraine material. Forty to 60 acres, and worked 20 to 30 feet to level of ground water.
Grade: Core sand. No. 868, top strata; No. 869, lower strata.

Lab. No.: 869.—See 868.

Lab. No.: 870.
Owner: John A. Smith, Kilbourn, Wis.
Formation: Terminal moraine material. Fifteen to 20 acres. Thickness not determined.
Grade: Core sand.

Lab. No.: 871.
Owner: L. J. Pierson Mineral Co., Ablemans, Wis.
Formation: Glacial lake deposit. Ten acres owned by the operating company, but the material is much more extensive.
Grade: Molding sand. No. 871 is a mix of 8 foot face with a quarter of a shovel of clay. No. 872 is top 5 feet of the pit. No. 873 is the lower 5 feet of the pit.

Lab. No.: 872.—See 871.

Lab. No.: 873.—See 871.

Lab. No.: 874.
Owner: The North Freedom Silica Company, L. J. Pierson, Pres., Ablemans, Wis.
Formation: Cambrian sandstone. Bluff, 7 acres in extent, stands 35 feet high.
Grade: Steel sand.

Lab. No.: 875.
Owner: L. J. Pierson Mineral Co., Ablemans, Wis.
Formation: Glacial lake deposit. The deposit extends 100 yards along the Chicago and Northwestern Railroad tracks and about the same distance back from the tracks. No. 875 is an 8 foot run of the bank. No. 876 is a 4 foot run of the bank above No. 875.
Grade: Molding sand and cupola clay.

Lab. No.: 876.—See 875.

Lab. No.: 877.
Owner: Walsh Sand & Gravel Company, Burlington, Wis. This pit is at Merrimac, Wis.
Formation: Terrace material along Wisconsin River. Eight to 10 acres 2 feet thick.
Grade: Medium to heavy molding sand.

Lab. No.: 878.
Owner: William Taylor, Merrimac, Wis., operated by the Walsh Sand and Gravel Co., Burlington, Wis.
Formation: Terrace deposit. This material covers about 5 acres and has a maximum thickness of about 3 feet.
Grade: Light molding sand.

Lab. No.: 879.—Same as 878.

Lab. No.: 880.—Same as 878.

Lab. No.: 881.
Location: This sample was collected at the Gisholt Machine Company, Madison, Wis., and is No. 5 Black Hawk Molding Sand produced by Manley Bros., of Rockton, Ill.

Lab. No.: 882.
Location: This sample was collected at the Gisholt Machine Co., Madison, Wis., and is Hardware Molding Sands, produced by Manley Bros., of Rockton, Ill.

Lab. No.: 883.
Owner: Paul Schroeder, R. R. No. 2, Maxomanie, Wis.
Formation: Terrace above Wisconsin River. Forty to 50 acres, 10 inches to 1 foot thick.
Grade: Not used.

Lab. No.: 884.
Owner: Not determined.
Formation: Sand dunes on a terrace above the Wisconsin River. These deposits cover about 100 acres north and south of the town of Arena and are of unlimited thickness.
Grade: Not used.

Lab. No.: 885.
Owner: The section where samples were taken is owned by R. L. Reymann.
Formation: Wind blown deposits along the bluffs of the Wisconsin River. These deposits extend along the bluffs for many miles.
Grade: Not used.

Lab. No.: 886.—Same as 885.

Lab. No.: 887.
Owner: Brother of H. Teasdale.
Formation: Terrace along the LaCrosse River. Covers several acres and is 4 to 6 feet in depth.
Grade: Used as a building sand.

Lab. No.: 888.
Owner: Fred Ebner, R. R. No. 2, LaCrosse, Wis.
Formation: No. 888 loess and No. 889 Cambrian sandstone. Deposits similar to No. 888 cover the bluffs in this section in many places, and vary greatly in thickness. No. 889 small quarry with 25 foot face.
Grade: No. 888, light molding sand. No. 889, core and steel sand.

Lab. No.: 889.—See No. 888.

Lab. No.: 890.
Owner: W. L. Hauser, Mondovie, Wis.
Formation: Terrace deposit. There appears to be about 100 acres underlain by sand, 3½ to 4 feet thick.
Grade: Not used.

Lab. No.: 891.—Same as 890.

Lab. No.: 892.
Owner: On the property of William Hurtley and also Jacob Thorsen.
Formation: Terrace deposit. About 75 acres of sand, 4 feet thick.
Grade: Not used.

Lab. No.: 893.
Owner: EauClair Sand and Gravel Co., EauClaire, Wis.
Formation: Terrace above the Chippewa River. The bank still contains 4 or 5 acres of material which is about 50 feet thick.
Grade: These samples represent sands which vary greatly in texture and can be used as core steel and blast sands.
Lab. No.: 894.—Same as 893.

Lab. No.: 895.—Same as 893.

Lab. No.: 896.—Same as 893.

Lab. No.: 897
Owner: Walsh Sand and Gravel Co., Burlington, Wis. Pit at Merrimac, Wis.
Formation: Ground moraine material. Material varies in depth and has a lateral extent of about 4 or 5 acres.
Grade: Medium to heavy molding sand.

Lab. No.: 898.
Owner: E. B. Robbins, R. R. No. 1, Box 40, EauClaire, Wis.
Formation: Terrace deposit above Chippewa River. One hundred acres about 1½ to 2 feet thick.
Grade: Not used.

Lab. No.: 899.
Owner: Not determined.
Formation: Cambrian sandstone. This sandstone is about 15 feet thick in this vicinity and covers all the round topped hills.
Grade: Not used.

Lab. No.: 900.
Owner: C. C. Randolph, East Troy, Wis.
Formation: Terrace of outwash material. Covers at least 50 acres, 1½ feet thick.
Grade: Not used.

Lab. No.: 901.
Owner: Ole Burns, Rockdale, Wis.
Formation: St. Peter sandstone. Small quarry, 10 to 12 foot face.
Grade: Core sand.

Lab. No.: 903.
Formation: This sample represents a pound of molding sand sent in by the Wisconsin Mineral Mining Company from a locality near Green Lake, in Green Lake County, Wis.

GEORGIA

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total			
1301	1 Mile S. W. Emerson	Iron Castings	.....	Tr.	1.24	1.48	2.60	6.04	12.44	14.60	16.56	21.04	24.04	100.04	7.0 9.1 11.1 12.5	..... 239 **258** 235	11.4 13.4 **20.0** 14.7
1302	1½ Miles North Flintstone	Pipe Molds	.....	.....	Tr.	2.00	34.00	19.20	9.96	4.64	4.86	7.36	18.00	100.02	3.9 6.5 7.2 10.1	..... **176** 173	13.4 44.0 **55.0** 45.0
1303	¼ Mile South Blowing Springs	Heavy Iron Castings	.....	.....	Tr.	2.70	17.60	11.26	4.04	5.08	5.54	15.74	37.68	99.64	•6.7 8.2 10.8 12.8	235 253 **292** 272	10.0 24.2 **27.0** 13.8
1304	3 Miles S. E. Ringgold	For Plow Points	.....	.....	.....	.48	15.96	12.50	9.14	8.86	13.08	13.76	25.80	99.58	7.2 9.1 10.8	284 **300** 293	19.5 **25.8** 21.8
1305	4½ Miles S.E. Ringgold	Iron Castings	.....	.....	.....	.90	12.88	11.40	8.34	10.56	10.60	23.10	22.20	99.98	6.8 8.8 10.8 12.8	264 **293** 261	8.2 17.3 **20.0** 10.7
1306	4½ Miles N. W. Cedartown	Iron and Brass	.....	.....	1.00	2.20	28.68	12.40	7.24	4.10	3.80	12.50	28.06	99.98	6.3 7.4 10.1 12.3	196 **252** 188	14.7 30.0 **55.0** 14.3
1307	.....	.....	.....	Tr.	1.12	7.00	33.58	14.06	8.44	4.10	4.76	10.30	16.64	100.00	4.2 6.0 7.8 9.8	125 **135** 133	11.0 30.0 **72.0** 67.0
1308	N. E. Of Terminal Station, Columbus	Cores and Rough Iron Castings	.....	Tr.	8.04	12.00	36.44	8.10	4.06	4.00	2.82	4.20	20.70	100.36	3.7 4.4 6.6 8.5	..... **243** 242 194	173 **264** 226 193
1309	Just S. of Columbus	Medium Size Iron Castings	.....	.....	Tr.	2.00	6.08	16.14	17.64	17.80	8.40	16.10	15.26	99.42	6.4 8.5 10.2 12.8	..... 179 **181** 170	14.7 17.3 17.3 13.4
1310	Just S. of Columbus	Medium Size Iron Castings	.....	.....	.....	.92	24.30	22.36	15.24	13.04	7.80	7.10	9.14	99.90	4.3 6.2 8.3 10.1	99 **114** 113	28 34 **42** 30
1311	Terrace, North Section of Columbus	Heavy Iron Castings	.....	.....	4.02	9.80	24.74	10.56	3.04	4.86	4.88	7.74	30.32	99.96	9.2 11.2 12.6 15.3	..... 252 **366** 316	61 **126** 93 44
1312	1 Mile N. W. Cusseta	Not used	.....	.50	2.04	20.20	28.64	14.74	6.44	2.30	1.44	2.30	21.16	99.76	4.0 6.2 8.3	..... **244** 242	67 **105** 93
1313	Howard	Not used in Foundries	.....	Tr.	4.60	35.80	30.98	10.90	4.74	2.12	1.54	2.04	7.20	99.72	2.5 3.1 4.0 6.1 7.7	..... **143** 103 94	156 **235** 193 178 162
1314	Howard	Not used in Foundries	.....	.44	4.20	35.94	42.04	11.34	3.46	.76	.46	.24	.86	99.74	Dry	.....	**235**
1315	Near Howard	Steel Castings	.....	.....	.64	22.24	43.24	24.48	6.80	1.14	.58	.30	.60	100.02	Dry	.....	212
1316	Junction City	Not used in Foundries	.....	.....	.96	26.02	45.90	16.14	6.26	1.74	1.06	.50	.90	99.48	Dry	.....	162
1317	3 Miles S. E. Junction City	Not used in Foundries	.....	.84	2.54	31.60	35.60	15.42	4.10	1.34	.94	1.60	5.30	99.28	4.0 5.7 7.3	67 **73**	235 **253** 205
1318	4 Miles S. E. Junction City	Not used in Foundries	.....	Tr.	3.40	8.54	41.24	18.14	6.28	6.08	2.24	1.66	12.44	100.02	2.6 3.7 4.0 6.4 8.2	.... **177** 158 131	108 **134** 119 126 90

GEORGIA—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total			
1319	2 Miles S of Gaillard.	Not used in Foundries....	.....	.....	4.02	11.94	55.00	14.68	4.00	3.80	.90	.98	4.76	100.08	2.9 3.8 5.9	79 81 77	212 226 212
1320	1½ Miles S. of Gaillard	Steel Castings.....	.....	Tr.	3.50	75.80	15.20	1.94	.70	.26	.24	.30	2.06	100.00	Dry	.....	341
1321	1 to 7 Miles S. W. Americus.....	Not used..	.....	.70	7.84	34.02	27.94	13.20	8.18	2.64	1.68	1.02	.80	100.00	Dry	.....	173
1322	1 to 7 Miles S. W. Americus.....	Not used..	.....	.....	Tr.	.88	6.50	32.54	19.86	13.00	3.40	5.76	17.86	99.80	6.8 8.7 10.8	..... 388 324	36 55 49
1323	Albany Junction.....	Silica Brick...	.....	.....	.36	22.74	54.54	18.74	2.40	.26	.16	.20	.60	100.00	Dry	.....	275
1324	1½ Miles N. Blakely	Not used in Foundries....	.....	.....	8.50	66.76	21.94	.76	Tr.	.54	Tr.	.34	1.00	99.84	Dry	.....	710
1325	2 Miles East Thomasville.....	Stove Grates and Heavy Iron....	.....	.....	.....	.72	11.50	20.16	18.52	13.84	10.80	10.54	13.80	99.88	9.0 11.2 13.3	..... 359 309	25 33 27
1326	N. W. Section of Moultrie.....	Iron Castings.	.....	.....	3.44	6.10	26.90	16.04	10.14	6.40	6.56	8.66	15.50	99.74	4.4 6.6 8.7	244 302 238	49 58 31
1327	N. E. of Albany.....	Light and Medium Weight Iron, Brass also.....	.....	.....	.....	.28	9.74	18.00	18.22	14.38	9.36	9.14	20.86	99.88	4.6 6.8 8.9	257 297 294	27.0 33.0 22.7
1328	½ Mile West of Chatterton.....	Not used in Foundries....	.....	.....	1.70	32.50	48.94	11.70	2.00	.50	.36	.44	1.24	99.38	Dry	.....	326
1329	1 Mile N. E. Lumber City.....	Not used in Foundries....	.....	.....	.44	27.90	50.46	15.54	2.76	.64	.50	.64	1.04	99.92	Dry	.....	212
1330	S. E. Lumber City....	Not used in Foundries....	.....	.....	.....	1.94	18.16	14.28	3.98	10.42	7.00	6.62	37.76	100.16	7.9 9.6 11.5	236 366 332	38 75 58
1331	7 Miles S. E. Jesup...	Not used in Foundries....	.....	.....	.80	3.30	7.18	14.68	25.08	11.16	5.54	5.22	26.78	99.74	4.1 6.9 9.0 11.0	..... 287 322 281	15.2 36.0 36.0 29.0
1332	River Sand, Savannah	Not used in Foundries....	.....	.....	.....	2.84	6.10	9.84	6.68	3.96	4.24	7.66	58.32	99.64	16.2 17.8 20.0	101 227	55 58 .....
1333	N. W. of Savannah..	Iron and Brass...	.....	.....	.....	.....	.52	12.00	44.74	11.08	4.40	4.34	22.56	99.64	4.0 5.3 7.0 9.2	..... 308 310 306	49 52 49 44
1334	S. W. of Augusta.....	Not used..	.....	.....	.....	1.18	1.86	1.64	4.76	6.46	12.24	24.38	47.48	100.00	10.0 11.7 13.7 14.0 16.0	244 256 251	6.5 8.5 30.0 42.0 .....
1335	S. E. of Dublin.....	Not used..	.....	.....	.....	2.98	5.92	9.22	10.74	8.38	8.36	10.72	43.54	99.86	11.4 13.5 15.4	259 311 298	63 85 67
1336	1 Mile East of Dublin	Not used..	.....	.....	2.28	43.30	48.18	3.72	Tr.	1.08	.28	.24	.86	99.94	Dry	.....	610
1337	Macon.....	Not used..	.....	.....	.....	.58	2.34	10.62	14.08	9.74	11.94	16.48	34.20	99.98	9.4 11.0 13.4 15.0 16.1	198 229 227	6.5 10.7 12.3 19.0 9.4

GEORGIA—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total			
1338	South of Macon.....	Iron Castings.....	.....	.....	Tr.	1.48	2.54	2.74	3.40	2.74	5.24	13.14	68.60	99.88	10.3 12.4 14.1 15.5	248 321 279	10.7 21.0 28.0 58.0
1339	1 Mile East Almon...	Iron and Brass...	.....	.....	.....	.54	3.58	7.44	9.80	8.08	9.16	15.70	45.60	99.90	9.9 11.4 13.6 16.1	212 214 223 245	5.3 7.2 8.2 17.3
1340	1 Mile East Almon...	Iron and Brass...	.....	.....	.....	1.10	1.24	12.14	8.34	5.90	6.30	11.20	53.00	99.22	4.0 6.5 8.2 10.0 11.8 13.6 16.5	.... 203 274 327 370	93 87 76 58 54 49 36
1341	½ Mile N. E. Almon...	Not used..	.....	.....	.....	1.36	7.24	9.10	9.44	6.46	7.30	11.26	47.66	99.82	9.5 11.4 13.1 15.4	223 291 328 320	33.0 49.0 58.0 44.0
1342	½ Mile N. Portердale..	Not used..	.....	.70	3.68	18.86	15.54	8.58	5.26	2.52	2.80	7.90	33.83	99.67	7.2 9.0 10.8	..... 293 266	122 156 88
1343	Gainesville.....	Iron and Brass...	.....	1.04	2.28	4.56	6.30	8.88	10.74	8.28	9.64	12.48	35.76	99.96	9.6 11.5 13.6 15.5	248 286 343 328	58 67 49 33
1344	1 Mile N. E. Bolton..	Iron Casting.....	.....	.....	Tr.	19.36	30.38	8.10	2.82	1.46	2.74	7.24	27.60	99.70	5.5 7.1 9.2	..... 288 278	87 93 67
1345	Chattahoochee River..	Not used..	.....	.....	.....	.94	15.68	21.34	14.00	7.70	6.54	10.28	23.24	99.72	4.8 6.5 8.8	..... 282 199	27 31 28
1346	1 Mile N. E. Bolton..	Not used..	.....	3.58	5.04	29.96	13.64	6.68	2.24	1.36	1.96	8.06	28.12	99.64	4.5 6.8 8.8	..... 281 262	122 212 162
1347	¼ Mile N. Utoy Creek.	Not used..	.....	1.64	1.46	6.88	26.96	11.54	4.68	2.76	3.14	5.86	34.62	99.54	5.0 7.2 9.0 11.8	..... 240 304 291	87 90 62 28
1348	1 Mile S. Utoy Creek.	Not used..	.....	.70	1.20	8.30	27.74	14.94	5.44	2.64	3.08	3.74	30.18	98.96	5.0 7.4 9.3	..... 291 289	72 72 58

IOWA

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
1101	Marshall Co. 4 miles E Marshalltown	Molding	.....	.....	.....	1.92	57.80	27.90	7.34	1.34	.34	.10	2.82	99.56	480	2.0 2.4 3.5 5.7	121 100 88 85	185 178 167 156
1102	Marshall Co. Marshalltown	Core	.....	.....	.30	1.02	1.38	1.54	1.28	1.48	6.90	45.70	39.76	99.36	3296	4.7 5.8 6.7 8.5 10.5 12.0 13.7	326 336 290 273	1.4 4.2 4.4 4.4 7.0 7.7 7.7
1103	Floyd Co. 300 yards N. Floyd Station	Molding	.....	.....	.....	.78	4.24	1.80	1.48	1.72	11.34	51.38	24.00	99.74	3104	4.7 6.6 8.2 9.7 12.6	..... 268 257	3.1 3.5 4.4 9.4 7.7
1104	Floyd Co. Nora Springs	Molding	.....	.....	.50	9.34	29.00	12.88	5.34	4.68	7.24	13.34	17.02	99.34	2176	3.2 4.4 6.3 8.3	240 288 290 275	40 50 49 42
1105	Clinton (Harrison Rd.)	Molding	.....	.....	.....	.94	8.08	31.90	15.88	10.10	12.28	12.46	7.76	99.40	560	5.9 7.6 9.6	131 140 131	17.8 19.5 15.7
1106	Clinton	Molding	.....	.....	.....	.24	4.78	13.38	9.84	20.30	19.20	23.14	8.26	99.14	832	4.5 5.3 8.0	160 142 140	27.0 25.8 24.2
1107	Cedar Rapids (Oak Hill)	Molding	.....	.....	.....	.48	6.28	7.64	6.78	5.50	13.80	39.14	20.10	99.72	1824	3.3 3.9 6.0 8.1	248 229 197 178	8.2 9.0 8.5 7.9
1108	Des Moines	Molding	.....	.....	.....	.26	6.00	14.06	15.00	13.44	18.80	18.98	12.64	99.18	2464	4.3 6.3 8.4 10.3	..... 247 230	9.0 13.0 21.8 17.3
1109	Jasper Co. 1 mile S. E. Reasnor	Molding	.....	.....	.....	Tr.	.68	1.98	3.44	5.74	15.24	57.20	17.00	99.28	1444	5.8 8.1 9.9 12.2	150 182 186 184	7.0 8.5 7.0 6.5
1110	Ottumwa (Franklin pit)	Core	.....	.....	.26	10.06	59.20	11.50	1.34	.80	.94	2.36	13.30	99.76	2240	4.2 6.4 8.8	345 375 290	193 219 126
1111	Muscatine	Molding	.....	.....	Tr.	.74	19.74	14.64	6.64	3.04	7.64	25.60	22.06	100.10	1764	3.0 4.1 6.2 8.2	..... 256 219 213	6.0 8.2 7.7 7.0
1112	.....	.....	.....	.....	Tr.	2.90	31.54	16.34	6.90	3.48	2.98	12.88	22.26	99.28	1764	3.0 4.1 6.1 7.9 10.0 11.5	..... 285 262 251	..... 12.6 19.0 33.0 40.0 1.1

Bold face type figures indicate greatest bond strength and permeability.

KENTUCKY

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
1001	Caldwell Co. Princeton	Friable Sandstone	.....	.....	.18	1.40	64.44	23.34	5.50	1.10	.50	.44	2.92	99.82	240	Dry	.....	102.
1002	Boyd Co. Ashland	River Deposit	.....	2.24	4.58	12.58	67.94	6.34	2.14	.70	.58	.64	2.36	100.10	224	3.3 5.9	....	440. 341.
1003	Boyd Co. Ashland	River Deposit	.....	.58	.38	2.34	61.20	24.54	4.48	1.68	1.70	1.30	1.76	99.96	96	Dry	.....	119.
1004	Greenup Co. Raceland	River Deposit	1.20	5.64	5.80	28.80	48.54	2.58	.54	.28	.34	.68	5.62	100.02	460	2.4 3.0 3.9 6.1	..... 135 108 73	358. 492. 417. 398.
1005	"		.....	Tr.	.14	1.74	93.30	2.84	.30	.10	Tr.	.14	1.42	99.98	140	Dry	.....	326
1006	Boyd Co. 2 miles s. w. Ashland	Decomposed Sandstone	.....	.....	.44	3.40	25.28	18.18	17.24	5.84	3.04	4.30	21.96	99.68	1344	3.8 6.4 8.4 10.7 12.2 14.2	..... 271 284 294 307 244	16.7 36.0 42.0 60.0 49.0 11.8
1007	Carter Co. 8 miles n. Olive Hill	Sandstone	.....	.....	.....	13.32	13.32	10.07	14.95	16.37	14.79	16.52	.....	99.34	284	Dry	.....	2.6
1008	Campbell Co. 1½ miles s. e. Newport	Molding....	.....	.....	.....	.....	.24	.34	1.08	1.88	11.20	44.20	41.10	100.04	2496	6.9 8.5 10.1	281 297 279	6.0 7.9 7.7
1009	"		.....	.....	.....	Tr.	.44	.30	.68	1.34	7.30	47.48	42.50	100.04	1656	6.0 8.3 10.1 11.4 13.2	..... 233 223	4.2 4.4 5.8 7.5 5.3
1010	"	Core.....	.....	.....	.....	Tr.	12.60	34.34	22.54	10.74	8.30	6.16	5.36	100.04	384	3.7 5.9 7.8	86 99 98	63. 85. 80.
1011	"		.....	.....	.....	Tr.	.98	3.90	4.44	6.68	17.90	45.54	20.26	99.70	1344	6.2 8.2 9.5	183 190 182	8.5 10.0 7.9
1012	"		.....	.....	Tr.	.14	5.44	12.54	11.80	11.80	18.70	26.68	12.16	99.26	780	6.2 7.8 9.8 11.7	142 143 146 147	13.8 29.0 21.0 19.5
1013	"		.....	Tr.	.18	.54	6.80	15.74	12.90	12.74	18.50	26.28	6.00	99.68	384	4.2 5.7 7.7 9.9 10.6	111 118 126 130 125	24.2 29.0 23.4 20.0 19.5
1014	Campbell Co. 10 miles s. e. Newport		.....	.....	.....	Tr.	6.54	46.78	13.44	3.00	2.04	3.04	25.26	100.10	2136	6.5 8.5 10.8 12.2	..... 371 354	47. 58. 67. 40.
1015	Kenton Co. Covington	General Foundry	.....	.....	.24	1.74	22.76	17.54	9.14	6.86	7.06	11.30	22.82	99.46	2176	6.7 8.6 10.8 12.0 12.9	261 355 336	14.3 22.7 36.0 55.0 40.0
1016	"	No. 3	.....	.....	Tr.	.08	.34	.78	6.14	13.20	28.96	36.78	13.76	100.04	804	5.9 7.9 9.9 11.7 14.5	143 151 152 156 161	10.0 17.8 11.0 11.0 7.0
1017	"	Heavy Machinery.	.....	Tr.	.84	6.04	37.90	13.40	4.44	1.68	1.80	3.54	30.72	100.36	2724	6.8 9.1 10.2 12.9	323 378 360	105. 142. 219. 178.

Bold face type figures indicate greatest bond strength and permeability.

KENTUCKY—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
1018	Campbell Co. Mentor.....	No. 3	.....	.....	.....	.....	.44	1.64	3.70	5.14	14.64	48.94	25.52	100.02	832	6.0 7.9 9.7	168 171 165	4.2 **6.0** 4.7
1019	Carroll Co. Carrollton.....	Core.....	.....	.....	Tr.	2.20	95.68	1.34	.24	.....	.....	.....	1.00	100.46	96	Dry	.....	358.
1020	"		.....	2.58	4.70	9.40	71.68	7.40	1.44	.30	.28	.48	1.50	99.76	140	Dry	.....	193.
1021	"	Molding. ..	.....	Tr.	.40	4.14	67.64	15.28	2.78	.88	.84	1.38	6.72	100.06	736	2.8 3.9 6.3	..... **178** 125	205. **243.** 219.
1022	Hardin Co. East View.....	Sandstone .	.....	.....	Tr.	.04	5.84	45.34	34.54	7.56	2.54	1.10	2.86	99.82	216	2.2 3.8 5.5	..... **95** 90	75. **86.** 80.
1023	Jefferson Co...	Molding....	.....	.....	.....	.....	1.04	12.90	14.88	7.64	7.00	38.44	17.70	99.60	704	5.8 7.9 8.7	167 **175** 168	6.7 **9.4** 8.2
1024	"	"	.....	.....	.....	.....	1.10	13.68	16.18	7.90	7.04	36.20	17.64	99.74	804	4.2 5.6 7.8 9.2 13.3	163 171 164	7.2 7.7 **8.8** 9.7 **10.7**

Bold face type figures indicate greatest bond strength and permeability.

NEW JERSEY

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
537	Warren Co. Delaware	No. 1 Delaware Sand	.....	.....	Tr.	.14	4.50	14.68	11.62	8.30	11.78	24.84	24.04	99.90	1088	4.5 6.7 8.8 9.5 12.0 13.9	..... **204** 198	4.2 5.8 7.1 11.0 13.8 6.7
538	"	No. 1A Delaware Sand	.....	.....	.....	.10	3.92	16.02	11.26	8.96	12.22	27.34	20.50	100.32	1024	4.1 6.1 8.4 9.6 11.8 14.3	..... **195** 178	3.5 6.0 10.3 14.3 **16.2** 7.0
539	"	No. 2 Delaware Sand	.....	.....	Tr.	.98	18.48	21.08	12.06	7.34	9.02	15.44	14.52	98.92	1024	4.0 5.7 7.9 9.7 11.7	119 **142** 132	10.3 23.4 36.0 **38.0** 36.0
540	Clayville	Molding	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1344	.....	.....	.....
541	"	Steel Molding	.....	.....	.....	Tr.	27.70	43.00	17.00	5.78	3.60	1.30	1.46	99.84	64	Dry	.....	88.
542	"	Molding Gravel	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	448	.....	.....	.....
543	Menantico	Fine Steel Molding	.....	Tr.	.46	6.30	30.88	8.40	1.94	.58	.44	.34	.80	100.14	64	Dry	.....	205.
544	Manumuskin Station	Steel Molding and Core	.....	.....	.98	25.40	59.46	11.34	1.70	.30	.10	.04	.50	99.82	32	Dry	.....	167
545	"	Sharp Silica Molding	.....	.....	.....	Tr.	69.64	23.44	3.74	.48	.60	.64	1.22	99.76	96	Dry	.....	119.

Bold face type figures indicate greatest bond strength and permeability.

NORTH CAROLINA

Lab. No.	Locality	Grade if Used	Fineness Test												Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total			
1450	Germanton	Not used	.....	.....	.64	4.70	12.38	13.30	10.06	5.40	7.86	14.00	31.16	99.50	6.6 8.9 11.0 12.6	210 221 192	9.7 16.2 17.8 3.5
1451	Germanton	Not used	.....	1.14	1.34	6.30	12.14	11.38	9.10	5.04	6.66	13.24	32.70	99.04	7.0 9.1 11.0 12.6	196 239 238	9.4 24.2 30.0 5.8
1452	Germanton	Not used	.....	Tr.	.60	5.34	12.88	15.08	9.40	6.60	8.20	13.74	28.66	100.50	4.7 6.5 8.4 10.3	130 177 174	6.3 12.2 19.5 13.4
1453	Germanton	Not used	.....	Tr.	.58	5.60	11.24	17.84	12.00	6.86	9.00	16.74	19.64	99.50	4.3 6.2 8.3 10.1	143 162 160	7.7 11.0 17.3 14.3
1454	Germanton	Not used	.....	.58	1.88	15.44	12.18	9.70	7.28	5.08	7.14	16.46	24.16	99.86	4.9 6.4 8.7 10.6	**127 181 168	10.7 20 42 27
1455	Mount Holly	Not used	.....	Tr.	Tr.	1.00	2.04	8.60	11.94	11.18	13.04	20.04	31.86	99.70	7.3 9.2 11.5 13.4	*.... 227 234 229	5.3 7.5 9.0 5.3
1456	Mount Holly	Not used	.. Tr.	Tr.	.38	1.14	1.78	4.86	6.74	6.20	11.14	19.26	47.00	98.50	10.7 12.5 14.3 16.9	283 308 329 300	11.0 30 47 42
1457	Mount Holly	Not used	.....	.....	.....	Tr.	.26	1.88	6.00	8.90	16.84	30.60	33.94	98.42	5.9 7.8 10.0 11.5 14.7	..... 199 204 254 208	3.1 5.1 4.7 4.0 3.7
1458	Lilesville	Not used	.....	.....	.90	25.98	27.94	19.60	7.60	2.98	1.96	2.46	10.36	99.82	3.3 4.5 6.6	* 266 190	108 193 108

*Too dry.
**Almost too dry

PENNSYLVANIA

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
631	Northumberland Co. 1 mile w. Riverside	Medium B-G	.....	.....	Tr.	.76	14.54	18.64	12.58	9.10	10.38	13.24	20.36	99.60	760	4.1 6.1 8.1 9.6 12.3	..... 248 236	12.2 21.8 33.0 4.00 13.4
632	Northumberland Co. 1½ mile w. Riverside	A.-D	.....	.....	.....	.....	.90	2.74	5.14	9.10	24.50	44.94	12.46	99.78	480	5.7 7.5 10.1	153 166 152	11.0 13.0 11.8
633	Northumberland Co. 1¾ mile w. Riverside	AAA-G	.....	.....	.....	.....	1.38	6.06	11.48	12.08	21.20	33.50	14.00	99.70	920	5.8 7.7 10.1	158 161 162	13.4 14.7 11.0
634	Montour Co. Grounds of State Hospital Danville	AAA-H	.....	.....	.....	.....	.80	1.74	5.68	9.50	24.86	46.18	11.22	99.98	544	3.6 5.8 7.8 9.9	..... 150 155 158	7.9 13.4 11.4 8.2
635	1 mile s. w. Bloomsburg	AA.—Selected	.....	.....	.....	Tr.	11.34	6.54	6.92	7.28	16.96	40.24	10.44	99.72	840	5.7 7.8 10.0	164 169 155	10.3 11.8 9.0
636	River Bottom Emporium Junction		.....	.....	Tr.	.20	16.80	19.10	15.14	9.36	10.94	12.34	16.00	99.88	1040	4.0 6.1 8.2 10.1	..... 176 169	12.6 19.5 30.0 27.0
637	"		.....	.....	.....	Tr.	12.48	18.64	16.34	10.28	11.06	11.90	19.16	99.86	1200	6.2 8.3 10.3 12.0 14.2	..... 190 201 205 180	11.4 14.3 14.7 19.5 10.3
638	River alluvium 5 miles S. Ridgway	Velvet No. 4	.....	.....	Tr.	1.24	16.00	17.74	13.94	8.38	10.36	13.76	18.44	99.86	860	6.1 8.9 10.0 11.8	199 207 185	15.2 21.8 29.0 19.0
639	5 miles S. Ridgway	Steel Foundry Sand	.....	.94	4.88	23.44	54.18	4.90	2.28	1.00	1.00	2.14	5.28	100.04	240	5.6	.....	610.
640	5 miles S. Ridgway	Loam	.....	.....	.....	.....	1.14	4.94	8.58	9.20	12.80	22.64	40.20	99.50	1088	6.6 8.0 10.4 12.4 13.5	245 276 249	1.9 2.9 4.7 5.6 6.3
641	3½ miles N. West Springfield	No. 1-V	.....	.....	Tr.	.84	.74	.76	6.24	18.40	27.18	23.20	22.30	99.66	840	6.6 8.5 10.8 11.7 14.0	205 210 204	7.5 8.5 10.7 12.6 7.0
643	River alluvium 5 miles S. Ridway	No. 1	.....	.....	.....	.....	.54	17.08	20.08	14.70	7.86	9.28	13.14	16.96	99.64	820	6.2 8.2 10.2 11.7	165 207 191	14.7 20.0 25.8 25.8
644	3½ miles N. E. West Springfield	No. 1-H	.....	.36	2.10	5.10	12.70	20.84	17.92	9.06	8.98	12.30	10.12	99.50	544	4.4 6.4 8.6 9.7 11.7	..... 178 171 165	10.7 14.3 17.8 21.0 19.0
645	3½ miles n. e. West Springfield	No. 3-E	.....	.38	3.54	12.48	29.40	8.64	3.24	1.72	3.66	13.10	23.56	99.72	640	7.0 8.3 11.0 11.6 13.1	209 214 213	9.7 17.3 33.0 88.0 24.2
646	Erie Co. 1½ miles w. Fairview	No. 6-FV	.....	9.14	45.00	15.60	1.44	.60	.54	.34	.96	9.44	17.10	100.16	680	5.9 7.8 9.8	164 148	48. 610. 610.

Bold face type figures indicate greatest bond strength and permeability.

PENNSYLVANIA—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
647	1½ Miles N. E. West Springfield.	No. 1½ Hoxie	.....	.20	1.96	5.18	16.74	42.00	9.58	3.96	5.04	8.24	6.96	99.86	352	4.5 6.6 8.8 9.2 10.0	..... 163 156	14.7 25.8 30.0 40.0 34.0
648	Northeast	Undeveloped	.....	.....	.28	.84	1.34	2.50	5.90	7.70	17.56	35.94	27.60	99.66	576	5.5 8.4 10.3	224 210	3.7 7.0 5.8
649	Crawford Co. J. L. Pfaff farm 1 Mile S. Atlantic		.....	.....	.....	Tr.	.18	2.40	7.30	9.14	21.18	45.30	14.20	99.70	400	3.6 5.7 7.6 9.8	116 149 144	6.7 10.7 14.7 10.7
650	Greenville	Crushed and washed S.S.	.....	2.94	2.58	14.28	52.84	14.78	5.64	2.08	1.40	1.14	1.86	99.54	120	Dry	.....	99.
651	"	"	.....	1.34	2.28	16.00	47.44	17.04	6.74	2.18	1.68	1.80	3.16	99.66	80	5.7	78	212
652	"	Fine Sand and Clay	.....	.....	.20	1.84	17.74	20.68	15.00	8.86	10.44	16.06	9.26	100.08	208	5.9 7.7 10.0 12.4	119 122 129 126	24.2 29.0 31.0 28.0
653	Quarry 1½ Miles S. W. Polk	Crushed Sandstone unwashed	.....	.58	10.80	78.34	2.58	.52	.50	.26	.38	.66	5.50	100.12	80	3.7 5.6 7.7	83 78	287. 440. 173.
654	Terrace of Allegheny River Oil City	No. 2	.....	Tr.	.44	5.14	8.90	9.88	11.96	10.70	16.90	21.10	14.98	100.00	520	2.5 3.7 5.9 8.5 10.7 12.4	..... 92 129 140 149 156	10.7 72.0 31.0 30.0 18.4 9.7
655	"	"	.....	Tr.	1.28	8.02	8.74	10.28	10.46	7.54	10.78	17.62	24.50	99.22	600	3.6 5.6 8.0 10.2	94 153 136	16.2 38.0 77.0 42.0
656	Falls Creek	Steel Sand, Crushed Sandstone	.....	1.78	9.14	29.58	33.36	9.50	3.44	1.28	1.28	2.56	7.96	99.88	480	3.3 5.6 7.5 10.0	78 87 68	138. 156. 167. 167.
657	"	Washed Sand	.....	.....	7.38	45.24	36.64	5.68	2.00	.54	.36	.50	1.62	99.96	144	Dry	.....	287.
658	.....	.....	.....	.....	7.30	37.74	23.18	5.38	2.70	1.28	1.68	4.18	16.26	99.70	480	3.6 5.7 7.4 9.0 11.5	144 172 145	29. 75. 193. 235. 21.
659	.....	.....	.....	.....	2.28	33.66	31.12	5.98	2.68	1.10	1.40	4.04	17.40	99.66	800	4.5 5.8 7.8	173 183 182	25.8 138.0 115.0
660	.....	.....	.....	.....	.50	32.50	31.00	6.44	3.14	1.50	1.88	4.54	18.26	99.76	440	3.7 5.8 7.8 9.5 12.3	131 173 168	16.7 58.0 128.0 138.0 1.9
661	.....	.....	.....	.....	Tr.	29.90	34.94	7.18	3.38	1.54	1.78	4.30	16.60	99.62	460	3.4 5.8 8.0 9.4	149 183 147	16.2 54.0 102.0 99.0
662	.....	.....	.....	.....	Tr.	4.74	38.68	12.70	6.68	3.58	3.68	7.44	21.72	99.22	448	3.7 6.0 8.0 9.7	..... 240 205	8.8 24.2 42.0 30.0

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN

Lab. No.	Locality	Grade if Used	Fineness Test												Dry Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
801	Milwaukee Co. Sec. 13, T. 5 N., R. 22 E					.10	.30	2.24	3.90	5.10	18.94	59.80	10.08	100.46	440	4.0 6.1 7.8 9.3	146 **157** 149	10.7 11.4 **12.6** 12.2
802	Racine Co. Sec. 17, T. 4 N., R. 23 E					.80	13.58	48.20	18.10	4.74	2.74	3.74	8.30	100.20	636	2.9 3.3 4.5 6.5 8.4	161 **162** 141 110 105	90. 93. **105.** 87. 72.
803	Racine Co. Sec. 17, T. 4 N., R. 23 E					.12	2.42	25.26	33.26	20.26	13.18	2.76	2.40	99.66	164	3.7 5.9 7.7 10.0	86 92 94 **101**	133. 87. 79. 62.
804	Racine Co. Sec. 28, T. 3 N., R. 20 E					.14	.98	30.18	37.04	7.64	2.44	1.32	2.38	16.96	99.08	2504	3.2 5.4 7.3 9.3	..... **327** 286 252	105. **126.** 126. 70.
805	Racine Co. Sec. 4, T. 2 N., R. 19 E				.42	1.10	6.58	40.36	15.26	4.78	1.80	1.50	3.90	24.38	99.08	3036	6.4 8.2 10.0 12.2	334 342 **400** 339	134. **162.** 138. 33.4
806	Kenosha Co. Sec. 25, T. 2 N., R. 19 E				2.44	5.92	10.28	31.48	8.84	2.38	1.00	1.16	5.38	30.82	99.70	3636	5.1 6.1 7.9 10.9 12.6	..... 294 336 382 **445**	219. **243.** 219. 185. 167.
807	Kenosha Co. Sec. 13, T. 1 N., R. 19 E				.34	.50	2.12	10.08	7.88	4.00	2.92	6.04	24.56	41.40	99.84	4220	7.6 11.2 12.6	279 324 **352**	85. **93.** 85.
808	Kenosha Co. Sec. 13, T. 1 N., R. 19 E				2.30	3.56	7.90	29.36	14.42	4.14	2.00	2.06	5.84	27.42	99.00	3336	1.6 4.8 6.2 7.2 10.2 12.5	.... 301 305 **384** 374	193. 212. 173. 156. 82. 47.
809	Rock Co. Sec. 36, T. 1 N., R. 13 E						1.52	19.46	25.08	5.54	2.40	3.28	17.74	24.94	99.96	2688	5.1 8.9 10.3 11.6	..... 316 337 **353**	80. 88. 61. 30.
810	Rock Co. Sec. 36, T. 1 N., R. 13 E						2.38	18.74	43.56	6.52	3.00	2.84	8.14	14.46	99.64	2076	2.3 4.8 6.3 8.5	Too dry **318** 290 252	56. **93.** 62. 55.
811	S. Beloit Illinois					.40	7.10	54.90	25.48	5.96	1.34	.60	.46	3.08	99.32	544	2.2 3.9 5.8 Dry	**119** 87 85	173. **178.** 173. 133.
812	Rockton Illinois	Hardware			.10	.22	.74	5.22	13.56	6.04	3.82	7.34	43.22	19.84	100.10	2236	4.6 6.5 8.6 10.0 11.5	**280** 222 207	5.3 5.6 **7.5** 5.8 4.7
813	Dane Co. Sec. 35, T. 7 N., R. 9 E						1.0	22.74	34.98	15.88	8.26	7.26	6.54	2.36	99.02	176	3.5 5.7 7.7	94 **96** 95	72. **87.** 67.
814	Rock Co. Secs. 21 and 22, T. 3 N., R. 12 E.						1.76	12.04	28.14	3.90	1.42	2.04	21.34	29.52	100.16	3372	6.4 8.0 10.2 11.3	**280** 327 332 **351**	24.2 40.0 **73.0** 65.0
815	Rock Co. Secs. 21 and 22, T. 3 N., R. 12 E.						2.64	28.20	36.86	5.56	1.26	1.00	7.14	17.38	100.09	2000	2.4 3.7 5.8 8.1	..... 290 **315** 250	88. 112. 102. 70.
816	Waukesha Co. Sec. 2, T. 6 N., R. 17 E		2.60	1.78	2.96	15.34	34.74	8.54	2.16	1.06	1.32	5.70	24.34	100.54	2320	4.2 6.5 8.3	252 **350** 340	138. **193.** 185.

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
817	Waukesha Co. Sec. 17, T. 7 N., R. 17 E		5.00	3.08	4.32	26.84	27.54	11.64	.94	.36	.54	2.64	17.54	100.44	3104	7.0 7.8 10.6	348 **358** 304	376. **417.** 178.
818	Washington Co. Sec. 27, T. 12 N., R. 19 E					.06	.48	.50	1.30	6.14	29.08	48.74	14.60	100.90	240	1.6 3.6 5.5	..... 125 122	10.0 12.2 10.3
819	Sheboygan Co. Sec. 26, T. 15 N., R. 23 E					.36	2.32	89.96	6.60	.30	.06	.04	.70	99.71	40	Dry	.....	88.
820	Brown Co. Sec. 27, T. 24 N., R. 21 E			.32	.42	4.86	27.62	31.70	4.96	2.42	2.04	3.10	22.56	100.00	1960	5.6 9.0 9.9	283 **289** 255	185. **198.** 82.
821	Brown Co. Sec. 27, T. 24 N., R. 21 E					2.32	28.96	43.72	10.36	4.24	2.80	2.02	5.66	100.08	320	3.6 5.4 7.4	92 **97** 94	112. **119.** 102.
822	Winnebago Co. Sec. 29, T. 20 N., R. 18 E					.14	6.66	12.86	13.88	10.28	13.24	20.46	21.96	99.48	1604	4.3 6.0 7.8 9.7	196 **263** 229	12.2 13.4 **14.3** 13.8
823	Winnebago Co. Sec. 29, T. 20 N., R. 18 E			.34	.28	.94	2.58	11.94	9.82	7.54	14.22	24.14	28.26	100.06	2120	6.3 7.1 7.7 9.7 11.1 11.6	253 276 295 **303** 287	13.8 14.3 16.2 24.2 **40.0** 15.7
824	Winnebago Co. Sec. 29, T. 20 N., R. 18 E				.14	.54	1.86	12.44	9.44	8.28	14.80	25.26	27.68	100.44	2860	5.7 7.1 7.5	264 **297** 282	27.8 **34.** 23.4
825	Winnebago Co. Sec. 29, T. 20 N., R. 18 E			.12	.08	.24	10.12	57.44	16.08	6.30	4.48	3.64	1.76	100.26	200	Dry	.....	58.
826	Outagamie Co. Sec. 34, T. 22 N., R. 15 E					.14	38.66	40.64	14.04	3.44	1.14	.94	1.04	100.04	160	Dry	.....	61.
827	Waupaca Co. Sec. 6, T. 22 N., R. 15 E			.36	.34	1.34	4.22	35.84	18.14	8.56	7.32	6.98	16.18	99.28	1560	3.9 4.0 5.5 8.3	272 **288** 255	46. 52. **70.** 67.
828	Waupaca Co. Sec. 26, T. 23 N., R. 11 E			.32	.54	7.36	9.60	33.52	3.08	1.38	2.18	20.42	21.56	99.96	2720	4.6 6.2 8.7 9.1 9.3	300 **307** 285	19.5 36. **44.** **87.** 67.
829	Green Lake Co. Sec. 14, T. 17 N., R. 13 E					1.54	35.40	40.76	12.74	4.30	2.82	1.36	.86	99.78	120	Dry	.....	52.
830	Green Lake Co. Sec. 14, T. 17 N., R. 13 E					.74	23.80	41.82	19.12	8.08	4.46	1.40	.58	100.00	100	Dry	.....	52.
831	Green Lake Co. Sec. 14, T. 17 N., R. 13 E				.14	1.82	3.02	27.70	6.24	3.64	4.78	15.68	36.88	99.90	3472	4.7 6.0 8.3 10.5 11.8	241 298 331 337 **378**	32. 46. 90. **93.** 93.
832	Green Lake Co. Sec. 13 T., 17 N., R. 13 E	No. 3 L			.10	.54	2.22	13.56	7.02	5.18	12.10	28.60	30.66	99.98	2852	6.5 8.1 8.7 10.9 11.8 14.5	309 320 316	15.2 19.5 22.7 44.0 **65.0** 28.0
833	Green Lake Co. Sec. 11, T. 17 N., R. 13 E					.34	1.08	18.44	11.88	14.94	24.60	19.10	9.46	99.84	804	2.8 4.3 5.6 8.3 9.0	..... 190 176	19.0 19.5 20.0 **21.0** 12.6

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
834	Green Lake Co. Sec. 13, T 17 N.	No. 1				1.32	12.22	44.86	16.36	9.16	6.04	5.02	4.56	99.54	320	3.5 5.5 8.0	110 117 110	48. 61. 54.
835	Green Lake Co. Sec. 13, T. 17 N., R. 13 E					.58	8.20	53.92	21.48	9.40	4.60	.70	.74	99.62	360	Dry		61.
836	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 3 H		40	.34	2.26	8.04	7.76	4.26	2.60	5.30	21.58	47.42	99.96	3036	6.3 8.0 9.6 10.1 12.6	275 287 336 364 350	30. 80. 90. 73. 63.
837	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 1 L				.36	7.38	30.72	17.54	13.66	10.90	10.38	8.42	99.36	472	2.8 4.5 5.5 8.3	 161 145 141	16.7 21.8 23.4 16.7
838	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 3 H				.58	8.50	17.16	11.64	9.90	11.26	20.28	20.50	99.82	1704	3.9 6.2 8.2	269 302 268	10.0 15.2 9.0
839	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 1				.26	6.66	28.48	19.28	11.92	12.08	12.80	8.16	99.64	440	3.1 4.0 6.0 7.7 8.9	 168 147 144 	16.2 21.8 22.6 23.4 22.7
840	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 2				.44	8.96	19.48	13.44	7.94	9.16	18.44	21.96	99.82	1676	6.8 8.2 9.6 12.2 13.3	217 225 190 	18.4 23.4 30.0 2.6 2.2
841	Winnebago Co. Sec. 18, T. 17 N., R. 14 E	No. 3				.74	9.60	21.40	10.44	7.40	8.74	21.44	19.96	99.72	2720	5.9 8.0 9.7	306 316 279	21.0 36.0 24.2
842	Winnebago Co. Sec. 19, T. 17 N., R. 14 E	No. 1				.38	11.70	22.46	19.00	12.38	12.28	11.94	9.68	99.82	608	4.8 5.7 8.3	136 140 133	20.0 28.0 18.4
843	Winnebago Co. Sec. 18, T. 17 N., R. 14 E	No. 2				.36	1.56	13.50	8.74	6.90	11.73	30.50	26.96	100.26	1560	4.4 6.0 8.2 9.8 12.0	 232 222 	4.7 6.5 10.0 13.8 9.0
844	Winnebago Co. Sec. 18, T. 17 N., R. 14 E	No. 3				.48	10.80	25.96	8.88	5.96	7.46	20.44	19.52	99.50	2280	4.3 6.1 8.2 9.5 11.5	262 309 272 	12.6 18.4 25.8 29.0 10.7
845	Winnebago Co. Sec. 18, T. 17 N., R. 14 E	No. 2 Blended			.08	.56	8.60	11.98	9.72	9.94	12.14	23.58	23.48	100.08	1536	4.4 6.3 7.9 9.8 11.8	202 230 224 	7.2 11.0 13.8 14.7 11.8
846	Winnebago Co. Sec. 18, T. 17 N., R. 14 E	No. 3 Blended		.76	.86	3.06	3.00	21.98	6.56	3.46	5.98	25.96	28.40	100.02	2672	4.4 6.6 8.7 9.5	244 288 284 	16.2 30.0 44.0 42.0
847	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 1				.16	.92	34.64	21.60	13.24	14.54	9.24	4.64	98.98	504	3.0 3.7 5.8 8.0	150 176 123 119	33. 44. 49. 28.
848	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 2				1.24	.54	1.80	27.56	12.58	8.18	7.66	16.82	24.24	100.62	1504	3.8 5.9 7.9 9.7	 237 198 	8.8 20.0 40.0 27.0

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN —Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
849	Green Lake Co. Sec. 13, T. 17 N., R. 13 E	No. 3			.06	.50	2.00	28.04	13.42	8.48	8.58	16.64	23.22	100.94	1536	4.1 6.2 8.3 9.8	..... 274 239	12.6 33.0 **42.0** 22.7
850	Green Lake Co. Sec. 1, T. 17 N., R. 13 E					.72	29.98	50.34	11.24	3.20	2.28	1.20	1.34	100.30	300	Dry	.....	67.
851	Fond Du Lac Co. Sec. 20, T. 16 N., R. 14 E				.66	10.02	41.52	37.08	6.26	1.38	.70	.46	.54	98.62	280	Dry	.....	93.
852	Fond Du Lac Co. Sec. 20, T. 16 N., R. 14 E			.20	.14	4.10	34.28	45.22	11.90	2.20	.94	.38	.72	100.08	400	Dry	.....	67.
853	Waushara Co. Sec. 18, T. 18 N., R. 12 E				.08	6.28	29.36	51.98	7.54	1.38	.72	.90	1.20	99.44	320	Dry	.....	67.
854	Green Lake Co. Sec. 3, T. 17 N., R. 13 E					1.98	32.94	39.40	13.44	6.00	3.48	1.60	1.10	99.94	300	Dry	.....	54.
855	Green Lake Co. Sec. 3, T. 17 N., R. 13 E					1.04	39.70	37.46	11.38	3.00	1.80	.68	4.86	99.92	144	2.5 3.5 5.6 8.0	..... 87 **95** 94	105. **112.** 105. 73.
856	Green Lake Co. Sec. 13, T. 17 N., R. 13 E					.50	10.00	43.54	17.44	9.00	8.20	6.28	4.94	99.90	544	2.8 3.9 5.5	..... 137 77	42. **50.** 44.
857	Green Lake Co. Sec. 15, T. 17 N., R. 13 E					3.48	35.18	49.20	7.78	3.24	.90	.16	.76	100.70	144	Dry	.....	80.
858	Green Lake Co. Sec. 15, T. 17 N., R. 13 E				.70	15.90	32.24	41.96	5.24	.80	.20	.08	.88	100.00	160	Dry	.....	146.
859	Green Lake Co. Sec. 15, T. 17 N., R. 13 E				1.14	19.60	48.30	25.60	3.40	.44	.14	.08	1.24	99.94	400	Dry	.....	185.
860	Green Lake Co. Sec. 15, T. 17 N., R. 13 E				1.68	30.98	15.14	48.14	2.28	.24	.10	.08	1.16	99.80	360	Dry	.....	212.
861	Green Lake Co. Sec. 15, T. 17 N., R. 13 E					.58	27.96	54.08	12.04	3.28	1.52	.34	.36	100.16	8	Dry	.....	75.
862	Green Lake Co. Sec. 17, T. 17 N., R. 13 E				.30	16.84	62.90	15.88	2.64	.62	.30	.20	.66	100.34	40	Dry	.....	122.
863	Green Lake Co. Sec. 1, T. 17 N., R. 13 E					1.00	39.08	40.50	11.20	3.44	2.44	1.10	1.46	100.22	72	Dry	.....	70.
864	Green Lake Co. Sec. 1, T. 17 N., R. 13 E			.50	.16	.80	1.50	37.68	5.50	2.44	3.90	14.36	33.02	99.82	2620	4.5 6.7 8.7 9.4 11.3	..... **339** 330	50. 61. 67. **96.** 54.
865	Green Lake Co. Sec. 36, T. 15 N., R. 13 E				.20	3.28	35.24	51.48	7.40	1.10	.54	.34	.58	100.16	8	Dry	.....	90.
866	Columbia Co. Sec. 27, T. 12 N., R. 9 E				.08	3.82	.88	85 22	5.70	1.72	1.04	.32	1.30	100.08	32	Dry	.....	105.
867	Columbia Co. Sec. 27, T. 12 N., R. 9 E				.14	5.76	.80	78.68	8.44	2.50	1.62	.62	1.26	99.82	40	Dry	.....	108.

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
868	Columbia Co. Secs. 28 and 33, T. 12 N., R. 9 E.	.....	.....	.....	.....	.17	12.32	81.52	4.00	.76	.36	.22	.62	99.97	40	Dry	.....	108
869	Columbia Co. Secs. 28 and 33, T. 12 N., R. 9 E.	.....	.....	.....	.....	.36	17.08	61.84	13.10	4.60	1.68	.46	.96	100.08	56	Dry	.....	65.
870	Columbia Co. Sec. 2, T. 13 N., R. 6 E	.....	.....	.98	1.48	30.04	46.78	17.96	1.28	.18	.14	.10	.72	99.66	8	Dry	.....	173.
871	Sauk Co. Sec. 32, T. 12 N., R. 6 E	.....	.....	.....	.....	.60	1.00	29.02	24.14	13.72	8.30	12.72	9.90	99.40	1456	3.7 5.9 8.0 9.4	..... **152** 129	27.8 **38.0** **46.0** 21.8
872	Sauk Co. Sec. 32, T. 12 N., R. 6 E	.....	.....	.....	.....	.54	1.06	24.24	21.74	13.74	7.22	15.69	15.18	99.68	1752	3.8 6.1 8.1 9.7	**265** 208 194	18.4 **38.0** **46.0** 17.8
873	Sauk Co. Sec. 32, T. 12 N., R. 6 E	.....	.....	.....	.18	1.80	.62	37.34	28.18	14.12	7.68	5.10	4.74	99.76	672	2.6 3.6 5.6	..... **108** 107	44. **52.** 48.
874	Sauk Co. Sec. 15, T. 11 N., R. 5 E	.....	.....	.26	1.94	4.74	.58	80.42	8.56	1.36	.62	.20	1.14	99.82	72	Dry	.....	88.
875	Sauk Co. Sec. 28, T. 12 N., R. 5 E	.....	.....	.....	.36	.42	16.82	11.90	1.72	7.44	6.14	35.60	19.04	99.44	2200	3.6 5.4 7.7	..... **243** 197	6.0 **10.7** 9.0
876	Sauk Co. Sec. 28, T. 12 N., R. 5 E	.....	.....	.....	.....	.40	.04	5.48	3.40	3.06	5.42	40.96	41.56	100.32	5400	7.0 8.9 10.5 12.1	297 **355** 308	7.9 **8.8** **11.8** **29.0**
877	Sauk Co. Sec. 2, T. 10 N., R. 7 E	.....	.....	.24	.82	1.82	.28	46.86	12.50	5.96	4.74	7.94	18.44	99.60	2328	4.3 6.2 8.1 9.6	334 **336** 280	47. **75.** **90.** 49.
878	Sauk Co. Sec. 35, T. 11 N., R. 7 E	.....	.....	.....	.....	.....	.50	18.18	26.98	19.30	13.00	12.14	9.80	99.90	560	3.9 6.2 8.0 9.6	141 **148** 136	21.8 **23.4** **29.0** 17.8
879	Sauk Co. Sec. 35, T. 11 N., R. 7 E	.....	.....	.....	.....	.18	.40	23.64	27.34	13.90	10.70	11.70	11.60	99.46	1120	2.6 3.4 4.9	..... **233** 200	27. **32.** **29.0**
880	Sauk Co. Sec. 35, T. 11 N., R. 7 E	.....	.....	.....	.....	.28	1.54	22.64	28.08	15.52	10.20	9.38	11.84	99 48	944	2.5 4.1 5.4 7.6	..... **161** 147 129	27. **31.** 29. **19.5**
881	Rockton Illinois.....	No. 5 Blackhawk.....	.....	.....	.....	.46	.54	38.86	12.04	4.44	5.10	16.54	21.68	99.66	2400	4.4 6.1 8.2 9.9	257 **316** 301	99. **142.** 96. 50.
882	Rockton Illincis.....	Hardware...	.....	.24	.46	.60	.44	9.30	4.54	4.00	6.58	48.96	24.76	99.88	2760	4.4 6.4 8.2	..... **252** 226	4.7 **6.0** 5.6
883	Dane Co. On line of Secs. 3 and 10, T. 8 N., R. 6 E	.....	.....	.....	.40	2.18	10.80	34.26	7.32	2.74	2.92	10.90	28.30	99.82	1766	6.3 8.1 10.2	274 284 **308**	22.7 **42.0** **46.0**
884	Iowa Co. Sec. 16, T. 8 N., R. 5 E	.....	.....	.....	.....	.60	41.44	47.44	7.32	1.42	.40	.16	1.00	99.78	48	Dry	.....	85.
885	Sauk Co. Sec. 6, T. 8 N., R. 4 E	.....	.....	.....	.....	.....	.94	86.52	8.72	1.84	.74	.20	1.04	100.00	224	Dry	.....	115.

Bold face type figures indicate greatest bond strength and permeability.

WISCONSIN—Continued

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
886	Sauk Co. Sec. 6, T. 8 N., R. 4 E					8.56	25.60	55.30	5.56	2.00	1.24	.52	1.26	100.04	176	Dry		173.
887	Monroe Co. W. side, Sec. 24, T. 17 N., R. 4 W.				.18	2.06	10.32	66.98	13.76	3.66	1.20	.38	1.10	99.64	88	Dry		65.
888	LaCrosse Co. Sec. 34, T. 16 N., R. 7 W.				.18	1.94	10.74	4.58	2.94	2.18	5.20	33.10	39.02	99.88	3200	6.9 9.0 11.2 14.3	290 299 **337** 321	10.3 16.7 **27.0** 16.7
889	LaCrosse Co. Sec. 34, T. 16 N., R. 7 W.				.74	8.24	2.70	77.20	6.72	2.34	.82	.22	.66	99.64	40	Dry		88.
890	Buffalo Co. Sec. 2, T. 24 N., R. 11 W.				.50	8.64	10.18	25.46	7.36	5.12	6.00	19.68	16.60	99.54	1920	3.4 4.0 6.0 8.1	 **278** 258 256	21.8 22.7 **46.0** 42.
891	Buffalo Co. Sec. 2, T. 24 N., R. 11 W.				.20	2.64	10.54	3.54	2.94	2.30	6.70	38.54	32.04	99.44	3400	5.5 6.4 8.6	 **331** 309	7.5 **21.0** 16.2
892	Buffalo Co. Sec. 12, T. 24 N., R. 11 W.					1.54	9.44	3.88	3.14	2.34	5.28	36.04	38.06	99.72	3200	4.4 6.9 8.4 11.2 12.3	 **333** 317 	4.0 6.3 8.5 17.8 **32.0**
893	Eau Claire Co.	Dry Core			3.28	54.54	.38	41.18	.24	.06			.40	100.08	24	Dry		287.
894	Eau Claire Co.	Blast		7.52	45.12	46.28	.48						.60	100.00	8	Dry		1620.
895	Eau Claire Co.			85.30	14.04	.10						.04	.50	99.98		Dry		2450.
896	Eau Claire Co.			.40	1.68	18.10	66.04	9.68	1.54	.38	.28	.28	.96	99.34		Dry		178.
897	Sauk Co. Sec. 2, T. 10 N., R. 7 E.			.70	.80	1.34	19.44	12.80	8.94	4.34	6.14	12.08	32.84	99.42	2176	3.6 4.8 6.7 8.8 10.9	 243 315 **334**	**49.0** **108.0** 80.0 75.0 56.0
898	Eau Claire Co.					.84	20.48	20.96	13.16	11.70	9.04	11.80	12.02	100.00	992	4.5 6.3 8.3	 **192** 170	13.8 **21.0** 19.0
899	Columbia Co. Sec. 28, T. 10 N., R. 8 E.					2.34	50.74	31.44	9.84	1.84	.34	.34	2.28	99.46	108	3.2		151.
900	Walworth Co. Sec. 16, T. 4 N., R. 18 E.			1.10	.60	6.04	43.28	13.28	4.34	2.14	2.44	5.54	21.56	100.32	2408	2.7 3.8 4.6 6.0 8.4 10.1	 305 **330** 323 	99. **126.** 105. 93. 85. 49.
901	Dane Co. Sec. 14, T. 6 N., R. 12 E.			.34	.32	3.14	41.60	38.54	11.00	1.90	.80	.70	1.50	99.82	144	Dry		93.
902	Winnebago Co. Sec. 6, T. 17 N., R. 14 E.					.32	44.88	36.10	10.74	3.32	1.54	.88	2.06	99.84		Dry		88.
903	Green Lake Co.						2.88	7.04	9.18	10.70	17.54	33.04	18.60	98.98				

Bold face type figures indicate greatest bond strength and permeability.

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